A

MATHEMATICAL GEOGRAPHY,

WITH A

SUPPLEMENT

CONTAINING AN

OUTLINE OF ASTRONOMY,

AND A

Manual for the Stellar Tellurian,

DESIGNED FOR COMMON SCHOOLS.

BY

ayson 1840-

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(TO BE USED EITHER WITH OR WITHOUT THE APPARATUS.)

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PREFACE.

It is not proposed to attempt the introduction of a new branch into Common Schools. Mathematical Geography is as really on the prescribed list of studies as Natural or Political Geography. The difference consists in the absence of a text-book on the former subject, the two or three pages, more or less, of naked, *unexplained* facts introduced into ordinary geographies, being all that the teacher can call to his aid.

This little volume is offered to Common Schools on the assumption that, if Mathematical Geography is worth learning, it is worth learning *thoroughly*; and that burdening the memory of the pupil with a few facts on the subject, which he does not understand without laborious explanations from the teacher, is not the true office of a school text-book.

The contents may be summed up briefly as follows:—(1) The Earth's Form; (2) Its Size; (3) Its Division by Circles; (4) Its Motions and their Results; (5) Its Relations to other Heavenly Bodies, particularly the Sun and Moon.

It will be seen that more ground is covered in this department than in ordinary geographies. In fact, all that part of astronomical science into which the earth enters as a prominent element, is assumed to belong legitimately to the subject; although great care has been taken not to introduce into the body of the book any topic which may not, by simple language and familiar illustration, be easily understood by those for whom the book is designed.

Many persons, however, cannot comprehend *combined motions* and their *results*, even though described in the fewest and simplest words. Their minds refuse to grasp changing relations of *place* and *direction* which their eyes do not behold. To attempt to teach such persons the mechanical part of Astronomy or Mathematical Geography, without something to aid the eye, is very much like attempting to teach ordinary persons to play the game of chess blindfold. Feeling, therefore, that text-book and apparatus should go hand in hand, the author has added to the Supplement a system of mechanical illustration, which, he hopes, will prove a welcome auxiliary to this most interesting branch of instruction.

This subject is more fully discussed, and the apparatus described, in the Introduction to the Manual, following page 110.

The feeling that the rich treasures of Natural Science should not be confined to the comparatively few who are permitted to enter our higher seminaries of learning, is becoming more and more prevalent. In many of our city Grammar Schools, Astronomy and Natural Philosophy are already parts of the regular course. May the feeling continue to grow, until popular education shall everywhere become more liberal! Let no thoroughness be sacrificed in the elementary branches; but every true teacher recognizes a distinction between *thoroughness*, and protracted drilling upon *unimportant details*. Pupils may memorize hundreds of the latter, and yet possess no thorough knowlege of *principles*. If true economy were more generally practiced in this respect, in Common Schools, is it not probable that much time might be saved for a wider range of study?

The Mathematical Geography alone is designed for Common and Grammar Schools; if taken, however, in connection with the Supplement, and the author's Uranography, the whole forms a course in Astronomy, sufficiently complete for most High Schools and Academies; while the Stellar Tellurian, and the Celestial Hemispheres (see note at bottom of p. 106), accompanying these publications, furnish the means for thorough illustration of the whole science.

Most cordial thanks are due to Prof. John Brocklesby of Trinity College, for careful examination of proofs, and many valuable suggestions and corrections.

TO TEACHERS.

In many Common Schools, the time is so largely appropriated to other subjects of study that but little is left for Mathematical Geography. Yet there are but few who will not admit the great importance of this branch, and who would not gladly see it occupy a little of the time so lavishly expended in memorizing the countless details of the other two departments of Geography. The majority of teachers will admit that the knowledge thus gained, of the grandest and most comprehensive facts regarding our planet, would much more than compensate for the loss of a few minor details relating to its surface.

This book is condensed from a larger one, with a similar title, by the same author. Lest, even in its reduced form, it should be found too voluminous for some of the classes for which it is designed, the matter which can best be dispensed with, is rendered in finer type. The remainder, certainly, is calculated to consume very little time; while it is still designed to present the outlines of the branch more fully than they are presented in ordinary geographies.

As one glances through the following pages, certain topics touched upon may seem too far advanced for young pupils; but a more careful examination will, it is thought, show that these are so simplified by familiar illustration, especially with the apparatus, that their introduction is fully warranted.

The matter is arranged to be recited either upon the "topical method" or by questions, as the preference of the teacher and the age and capacity of the pupil may dictate.

The addition of a Manual for the Stellar Tellurian was an after-thought. The writer has since made use of this apparatus in the presence of hundreds of pupils, and the eager interest and quick apprehension with which they invariably receive its revelations, warrant him in commending it most heartily to the examination of teachers.

CONTENTS.

SECTION FIFTH.—THE INCLINATION OF THE EARTH'S AXIS.

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SUPPLEMENT.

CERTAIN MORE DIFFICULT PRINCIPLES OF MATHEMATICAL GEOGRAPHY.

OUTLINE OF ASTRONOMY.

CONTENTS OF MANUAL.

(*Following page* 110.)

INTRODUCTION.

1. A Point has position without length, breadth, or thickness.

2. A Line has length without breadth or thickness.

3. A Surface has length and breadth without thickness.

4. A Solid has length, breadth, and thickness.

5. A Straight Line does not change its direction at any point.

6. A Curved Line changes its direction at every point.

7. A Plane is a surface, upon any part of which a straight line may be drawn. *Ex.*, the surface of a perfectly smooth floor.

8. A Circle is a plane bounded by a curved line, all points of which are equally distant from a point within, called the *center*. (See § 14.)

9. *The Circumference*[1] *of a Circle* is the curved line which bounds it.

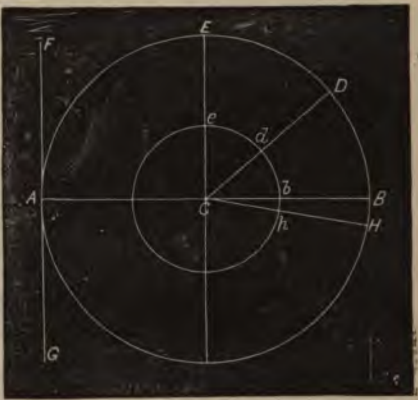

Fig. 1.

10. *The Diameter of a Circle* is a straight line drawn from the center both ways to the circumference, as AB.

11. *The Radius*[2] *of a Circle* is a straight line drawn from the center to the circumference; as CE, CD.

12. *An Arc of a Circle* is any part of the circumference; as ED, BH.

13. *A Degree of a Circle* is one-three hundred-and-sixtieth of its circumference. The word *degrees* is denoted by a small circle, placed at the upper right of a number. Thus, 45 degrees is written 45°. Each degree is divided into 60 equal parts, termed minutes (′); and each minute, into 60 equal parts, termed seconds (″).

(1.) Circumference; *circum*, around, and *ferens*, bearing.
(2.) Radius; *radius*, a wheel-spoke, a ray of light.

14. Although the term *circle* strictly refers to the plane surface included within the circumference, it is more frequently made to refer to the circumference itself, and will be so used in the following pages.*

15. An Angle is the opening between two lines that meet, the point of meeting being called the *vertex* of the angle. An angle is generally distinguished by three letters, one at the end of each line and the other at the vertex. In reading the angle, the latter is put between the other two. *Ex.*, ECD, BCH, Fig. 1.

16. *An Angle is measured* by the arc of a circle included between the lines forming the angle, the center of the circle being at the vertex, and its radius being of any length. Thus, the angle ECB is measured by the arc EB or the arc *eb*, both of which contain the same number of degrees, viz., $\frac{1}{4}$ of 360°, or 90°. We say, therefore, that the angle ECB, or *eCb*, is an angle of 90°.

It should be strongly impressed that the length of the lines forming an angle has nothing to do with determining its magnitude. The angle at the corner of this page, for example, is nearly four times as large as that formed by the equator and ecliptic ($23\frac{1}{2}$°).

17. *A Right Angle* is an angle of 90° ; as ECB, the corner of this page, etc. The lines forming a right angle are said to be *at right angles with, or perpendicular to,* each other.

18. *The Perpendicular to a Plane* is a line perpendicular to any line that may be drawn in the plane to its foot. *Ex.*, The perpendicular to the plane of the ecliptic.

19. A Triangle is a surface bounded by three lines, and containing three angles. The sum of the angles of every triangle equals 180°.

20. *A Right Angled Triangle* contains one right angle, as BAC. The side opposite the right angle, BC, is called the *hypothenuse.* Of the other two sides, one, AB, is called the *base,* and the other, AC, the *perpendicular.*

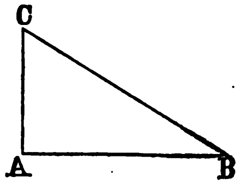

FIG. 2.

21. Parallel Lines and Surfaces are equally distant throughout their whole extent; as the lines of words upon this page, the covers of a closed book, etc.

22. A Sphere is a solid bounded by a surface, all points of which are equally distant from a point within, called the center.

23. *The Circumference of a Sphere* is the greatest circle that may be drawn upon its surface.

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* Whenever reference is made to the *surface* within the "circle," the words "plane of, etc.," properly qualified, will be used.

24. *The Diameter of a Sphere* is a straight line drawn from the center both ways to the surface.

25. *The Radius of a Sphere* is a straight line drawn from the center to the surface.

26. *Great Circles of a Sphere* are circumferences of the sphere. (See § 14.)

27. *Small Circles of a Sphere* are circles drawn around the sphere, smaller than its circumference.

It is evident that a great circle divides the surface of a sphere into two equal parts, and that a small circle divides it into two unequal parts. In the same manner, the *plane* of a great circle divides the whole sphere into two equal parts, while the plane of a small circle divides it into two unequal parts. (See Fig. 6, p. 25.)

28. *The Poles of a Circle drawn around a Sphere,* are two points in the surface of the sphere equally distant from all points of the circle. *Ex.* The poles of the earth are also poles of the equator and of each parallel.

29. Rotation is the movement of a body around its diameter, as the movement of a spinning top.

30. Revolution is the movement of a body or point around another body or point, as that of the stone around the hand, represented in Fig. 18, p. 49.

31. The Horizon is the line in which the heavens seem to meet the earth. The *sensible horizon* is seen from a point on the earth's surface. The *rational horizon* would be seen from the earth's center, if the earth were divided in halves. So small is the earth, however, compared with the heavens, that the sensible and rational horizons are as really the same as if they were those seen from the surface and center of a grain of sand.

32. The Zenith is the point in the sky directly overhead. The **Nadir** is the opposite point. These form the *poles of the horizon.* (See § 28.)

33. The Meridian[1] is a line extending from the north point of the horizon through the zenith to the south point. It is the meridian of the earth upon which we stand, extended to the sky.

34. Problems.

I. *Base and Perpendicular of a Right Angled Triangle given, to find the Circumference.*—Add the squares of the given sides, and extract the square root of the sum.

II. *To find the Circumference of a Circle or Sphere.*—Multiply the diameter by 3.1416.* When great accuracy is not required, $3\frac{1}{7}$ may be used as the multiplier.

III. *To find the Surface of a Sphere.*—Multiply the circumference by the diameter.

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(1) Meridian; *meridies,* midday.

* 3.14159265+

IV. *To find the Solid Contents of a Sphere.*—Multiply the surface by one-third of the radius.

35. The Universe.—All the suns (or stars), planets, comets, and meteoric bodies in existence, considered as one great whole.*

36. The Stars are suns, like our own, many of them much larger and more powerful in their light and heat. They are at immense distances from us, and from each other, and it is believed that each gives its light and heat to a number of planets.

37. A Planet is an opaque, spherical body, revolving around the sun or a star. *Ex.*, The earth.

A Moon is a small planet revolving around a larger planet. *Ex.*, The moon revolving around the earth.

38. A System is a collection, or group, of heavenly bodies, consisting of a sun (or star) with a number of planets revolving around it at different distances. *Ex.*, The Solar System, which has the sun for its center, and the earth for one of its planets.

39. Astronomy[1] treats of the Universe.

40. Geography[2] treats of the Earth.

41. Astronomical, or Mathematical, Geography treats of the Earth's relations to the Universe. It treats also of the Form and Size of the Earth; its division by Circles; and the art of constructing maps with the aid of these Circles.

Exercises.

1. Is the mark (.) a mathematical point, or does it simply *represent* one? (§ 1.)
2. What part of a smooth pane of glass represents a plane? (§ 7.)
3. What part of a wheel is its *radius?* (p. xi, note at bottom.)
4. What is the length of a degree of a circle 120 feet in circumference? Of a circle 1 foot in circumference? (§ 13.)
5. Which letter contains the greater angles, **W** or **X**? (§ 16.)
6. How many right angles are there in the walls of this room? (§ 17.)
7. Hold a pointer perpendicular to a straight line. To a plane. (§ 18.)
8. Can you draw a triangle containing more than one right angle?
9. Suppose you draw parallel lines of indefinite length; will they ever meet? (§ 21.)
10. Name certain great circles of the earth. (§ 26.) Small circles. (§ 27.)

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* Comets and meteoric bodies are described in the Supplement, § 221 and § 222.

(1) Astronomy; *aster*, a star, and *nomos*, a law.

(2) Geography; *ge*, the earth, and *graphe*, a description.

11. Point out, upon the globe, the poles of the tropic of Cancer. (§ 28.)
12. What is our zenith to those upon the opposite side of the earth? (§ 32.)
13. When the sun is on the meridian, what time of day is it? (§ 33.)

14. The base of a right angled triangle is 4 feet, the perpendicular is 3 feet; what is the hypothenuse? (§ 34—I.)
15. The diameter of a circle is 100 feet; what is the circumference?
16. The circumference of a sphere is 31,416 feet; what is the diameter? How many square feet in the surface? How many cubic feet in the sphere?

17. To what class of bodies does the sun belong? (§ 36.)
18. To what class of bodies does the earth belong? (§ 37.)
19. Is the north star a member of the solar system? The moon? (§ 38.)

20. To what branch of science does each of the following facts properly belong? (§ 39; § 40; § 41.)

Sirius is the brightest star.—The sun is more than 850,000 miles in diameter.—The earth is more than 1,200,000 times smaller than the sun. (§41.)—The earth's surface is about three-fourths water.—The earth is a flattened sphere.—The planet Mercury is about 35,000,000 miles from the sun.—The earth's diameter is about 8,000 miles.—The tropics are $23\frac{1}{2}°$ from the equator.—The earth is larger than the planet Venus. Venus is larger than Mars.—New York is in west longitude 74°.—The earth rotates in 24 hours.—Jupiter rotates in 10 hours.—Saturn has 8 moons.—The earth has 1 moon.

SECTION FIRST.—FORM OF THE EARTH.

CHAPTER I.

SPHERICAL FORM OF THE EARTH.

1. The Earth's Form is, very nearly, that of a sphere.

2. *What made the Earth round?*—The same cause that makes the rain-drop round, viz., *the mutual attraction of its particles.* Every particle of matter in the universe attracts, or tries to draw to itself, every other particle. This universal attraction is called the *Attraction of Gravitation*, or simply, *Gravitation.*

3. *How Attraction makes the Rain-drop round.*—Every one knows that drops of rain are produced by invisible particles of cloud or vapor running together. We may imagine two or three of these particles collecting and forming a little body, which attracts more powerfully that the single particles around it.* We may then imagine the surrounding particles gathering around this body as a center, until it becomes heavy enough to fall as a drop of rain. Now, the particles in the drop endeavor to approach as near as possible to the center, and thus form a *sphere*, just as a party of men, in crowding around an object, form a *circle.*

4. *How Gravitation made the Earth and other Heavenly Bodies round.*—In precisely the same way. We may imagine a time when the particles of matter which they contain were scattered through space, like particles of vapor in the air, and we may imagine those particles collecting around different centers, called centers of gravitation, until spherical masses were formed of all sizes, from that of the rain-drop to that of the sun itself.

NOTE.—*Questions on the matter in fine type, are in Italics.*

CHAP. I.—1. What is the earth's form? 2. What made it so? What is gravitation? 3. Explain the formation of a rain-drop. 4. Of the earth, etc.

* The more matter a body contains, the more powerfully it attracts.

5. *Illustration.*—A very simple but beautiful experiment shows the operation of the law which made the earth, moon, etc., round. Pour a little alcohol into a small tumbler, and drop a few drops of oil into it. The oil, being the heavier, will sink to the bottom; but, if water, which is still heavier, be added, it will descend below the oil, leaving the latter suspended in the midst of the mixture in one or more beautiful little globes. Be careful to add the water very slowly.

HOW WE KNOW THAT THE EARTH IS SPHERICAL.

6. First Proof.—*The Curvature of its Surface may be actually seen.*—We can see only a very small part of it, at once, even from the loftiest mountain; yet, even in that small portion, we may see its roundness, or *convexity.* When we look at a distant object upon the ocean or across a wide plain, we can see the intervening surface *rounding up* so as to conceal entirely the lower part of the object. This convexity is always found to be the same for the same distance (§ 23), which could not be the case except upon a spherical body. Whenever you are at the seaside near a great port, where many vessels are in sight at different distances, you may see this very satisfactorily illustrated: the more distant the vessels are, the lower they seem to sink behind the convex surface of the water.

7. *A more accurate Experiment, illustrating the same Manner of Proof,* consists in fixing three targets of equal height at equal intervals upon a plain, as a long sea beach, and

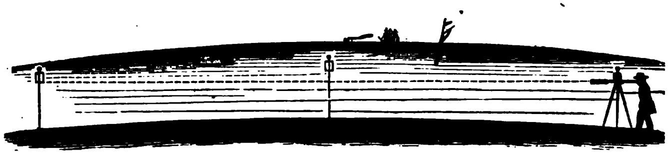

FIG. 3. *The Curvature of the Earth.*

"sighting" the elevation of the middle target above a perfectly straight line connecting the other two. The elevation is invariably found to be the same for equal distances.

8. Second Proof.—*Circumnavigation.*—Navigators have started from a certain point, and sailed constantly in the same general direction, until they have finally reached the very place from which they started. Now, if the

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5. *What experiment shows the operation of this law?* 6. How may we actually see the curvature of the earth's surface? 7. *How may this test be applied more accurately?* 8. How have navigators proved the earth to be round?

earth were of any other form than round, or if there were great edges or sudden turnings of any description in its form, these men could not have failed to discover indications of them.

9. Third Proof.—*The Horizon* (Introduction § 31) seems both to enlarge and to sink, as we ascend above the surface; whereas, if the earth were an extended plain, our field of view would not change, whatever our elevation. The horizon is also always circular, which would not be the case if the earth's form differed very much from that of a sphere.

We may illustrate this readily as follows: Cut a small circular hole in a card, and place it upon different parts of a globe. Supposing an observer to stand in the very center of the aperture, in each position, the circle around him represents his horizon. If some other object be taken to represent the earth, as a cube or cylinder, it will be seen that the hole in the card must be of different forms in order to fit different parts of its surface. That part of the globe which is seen through the aperture in the card, is so small as to appear perfectly flat. This explains why the surfaces of plains and the ocean seem flat to the ordinary observer.

It may be thought that the three proofs given above do not show *positively* that the earth is spherical—that it might be of some other rounding form, like that of an egg, for example, without materially affecting the appearances described. Such a supposition is shown to be incorrect from the three proofs which follow.

10. Fourth Proof.—*The Weight of a Body* is very nearly the same at all parts of the earth's surface, which could not be the case if the earth were not nearly spherical, since the same body grows heavier, the nearer it approaches (on the surface) to the center of the earth (Introduction § 22).

11. Fifth Proof.—*Eclipses.*[1]—In the course of the revolutions of the heavenly bodies, the earth sometimes passes exactly between the sun and the moon, casting a shadow on the latter. This shadow is *always circular*, showing that the earth is round *in every direction*. If it were round in only one direction, like a coin or medal, its shadow would be circular only when its flat surface exactly faced the moon. In all other positions, the shadow

9. In what two ways does the horizon prove the earth to be spherical? *How may the latter be illustrated?* Why are still other proofs desirable? 10. How does the weight of bodies prove the earth to be spherical? 11. Eclipses?

1 Eclipse, from a Greek word meaning to faint.

would vary from a straight line to an oval of different degrees of breadth, as may be easily shown by experiment. (*Manual* 52.)

12. Sixth Proof.—*Actual Measurement.*—It is not necessary that the whole of a figure be seen at once in order that it may be accurately measured. We have no doubt that the general outlines of countries which we see upon maps are correct. But it is a much more difficult and laborious undertaking to define the form of a single sea coast, than to determine that of the earth itself. Scientific men have, many times, calculated the distance from the center of the earth to different points upon its surface; and the result has always proved essentially the same.

13. Up and Down.—These directions are not fixed in space, like north and south, but depend entirely upon the position of the observer; and, since the earth is a sphere with observers upon all sides of it, *up* may be any direction *from* the center of the earth, and *down*, any direction *toward* the center. Apart from the earth or any other heavenly body, that is, in space, there are no such directions as up and down. One part of the universe is as "high" or "low" as any other part. We speak of the sun, at noon, as *up* above our heads, while those upon the opposite side of the earth speak of it, at the same moment, as *down* below their feet.

Exercises.

1. Suppose a cloud of dust were thrown from the earth into space with sufficient force to prevent its returning; what change would take place in the size of the mass? In its form? (§ 4.)

2. Suppose the horizon appeared to navigators sometimes circular, and sometimes oval; what would such appearances imply in regard to the form of the earth? (§ 9.)

3. What form will the shadow of a sphere, thrown upon another sphere, always assume?

4. What is always the form of the earth's shadow on the moon? (§ 11.) The earth is continually rotating; what, then, *must* be its form?

5. Some of the ancients supposed the earth to be an immense flat body, like a cheese; what may be supposed to have given them such an impression?

6. Suppose this were, in reality, the earth's form; where would bodies upon its surface weigh the most? (§ 10.)

7. If the surface of the ocean were flat, how long would a ship sailing from us remain in sight?

8. Which would disappear first, the rigging or the hull?

9. Which *does* disappear first? Why?

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12. Actual measurement? 13. What is meant by "up" and "down"? When the sun is "up" with respect to ourselves, how is it with respect to the people in China?

CHAPTER II.

DEPARTURES FROM THE SPHERICAL FORM.

14. The Earth's Form differs from that of a perfect Sphere in two Respects:

1. Its surface is uneven.
2. It is flattened at the poles.*

15. *The Amount of these Departures* is so slight that, if the whole figure of the earth could be seen at once, as by a spectator upon the moon, it would appear perfectly round, like the moon.

16. Unevenness of the Surface.—In order to be a perfect sphere, the earth's surface should be perfectly smooth; for hills and plains are not "equally distant from the center" (Introduction 22). Yet there are still higher mountains and deeper valleys on the moon, which, nevertheless, always appears to us perfectly round. All the hills, mountains, valleys, forests, cities, etc., on the earth, are so extremely small, compared with its own vast bulk, that they merely serve to *roughen* its surface in a slight degree. (*Manual* 1.)

17. *The principal Cause of the Unevenness.*—The earth was formerly a mass of melted matter. As the outer portions cooled, they hardened into a shell of solid rock, called the *crust*. This, in hardening, *shrank*, and thus formed mountains and valleys; just as a smooth apple becomes *puckered*, when it dries and contracts. Since then, volcanic action, which is nothing more than the *boiling* of the melted matter within the crust, has modified the form to some extent.

18. The Flattening at the Poles is due to the earth's rotation (Introduction § 29), which has caused those parts near the equator to bulge out, and those near the poles to sink correspondingly. (*Manual* 5.)

CHAP. II.—14. Is the earth a perfect sphere? 15. Does it differ very much from a perfect sphere? 16. In order that the earth should be a perfect sphere, what should be the character of its surface? To what extent do mountains and valleys affect its form? 17. *What produced mountains and valleys?* 18. What has caused the earth to be "flattened at the poles"?

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* Careful measurements have recently shown that the equator also is very slightly flattened upon two opposite sides.

19. *The Mathematical Name* of the figure thus produced, is *oblate spheroid.*

FIG. 4. *Oblate Spheroid.*

20. *Illustrations.*—1. If a slender needle be carefully passed through one of the oil globes described in § 5, and steadily turned, the globe will rotate upon it as an axis, and the flattening at its poles will be perfectly evident.

2. The apparatus shown in Fig. 5, strikingly shows the effect of rotation upon a spherical body. Two flexible hoops of brass cross each other at right angles, and through their points of intersection is passed a vertical rod. When the hoops are at rest, they occupy the position shown by the dotted lines; but, upon being rapidly rotated, they slide down upon the rod, and assume the spheroidal form.

21. *The Amount of the Flattening at the Poles.*—The difference between the polar and equatorial diameters of the earth is about 26 miles. Each pole, then, is depressed only about 13 miles, or $\frac{1}{610}$ of the whole diameter, a distance equal to only a little more than twice the height of a lofty mountain. (*Manual* 6.)

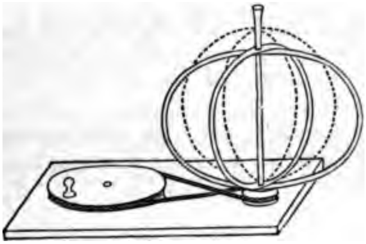

FIG. 5. *Effect of Rotation.*

PROOFS OF THE EARTH'S SPHEROIDAL FORM.

22. First Proof.—We have, as among the proofs of its spherical form, what is termed the argument of *analogy*, viz., all rotating bodies are subject to the law that flattens the flexible hoops (§ 20–2.) We know, from observations of the disks of other heavenly bodies, that they are obedient to the law; hence we reason that the earth must be so, likewise.

23. Second Proof.—*Actual Measurement.*—A method of measuring the curvature of the earth was given in § 7. Another method is given in § 59. It is found that this curvature is greatest at the equator, and that it grows less and less toward the poles, which renders the spheroidal form a *certainty.*

24. Third Proof.—*Weight.*—The nearer a body above the surface of the earth, is to the center, the more it weighs. It is found that a body weighs a

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19. What is the mathematical name of the earth's figure? 20. *How may we illustrate the earth's spheroidal form, and its cause? How does the apparatus (Fig. 5) show the effect of rotation?* 21. How much is the earth flattened at the poles? 22. How does analogy show that the earth is spheroidal? 23. Actual measurement? 24. Weight?

little more near the poles than at the equator; hence we reason that the poles must be nearer the center.*

Exercises.

1. Estimating the earth's diameter at 8,000 miles, what should be the thickness of a grain of sand, to represent a mountain 5 miles in height, upon a globe 6 inches in diameter? *Ans.* The height of the mountain is $\frac{5}{8000}$ of the earth's diameter. The thickness of the grain of sand must, therefore, be $\frac{5}{8000}$ ($\frac{1}{1600}$) of the diameter of the globe, or $\frac{3}{800}$ of an inch.

2. What thickness should be scraped from the poles of the globe, to represent the proper amount of depression? (§ 21.—*Manual* 6.)

3. What should be the width and depth of a scratch upon the globe, to represent a river $\frac{1}{2}$ of a mile wide and $\frac{1}{10}$ of a mile deep?

4. What would finally result, if the rapidity of the earth's rotation should be indefinitely increased? *Ans.* The earth would be shattered, and its fragments would be hurled into space (§ 97).

5. Of what material is the earth's axis composed?

6. Would the earth be a more comfortable or beautiful habitation for us, if its form were changed to that of a perfect sphere? If the irregularities were made very much greater than they are?

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* *Centrifugal force* (§ 98) would, of course, diminish the weight somewhat at the equator; but nice calculations show that this does not account for *all* the difference of weight in the two positions.

SECTION SECOND.—MEASUREMENTS.

CHAPTER I.

LATITUDE AND LONGITUDE.

25. Division of a spherical Surface.—The earth's surface contains about 200,000,000 square miles. The surface of a sphere cannot be laid out in squares or rectangles, like a well-planned city. How, then, shall we lay it out? The rotation of the earth furnishes us with certain fixed lines and points, by means of which we are enabled to lay out its surface even more easily than if it were a vast plane.

26. *Poles, Axis, Equator, etc., fixed by the Earth's Rotation.*—In a motionless sphere, no point is particularly distinguished from the rest, excepting the point in the center. When rotation begins, however, new relations are immediately established. Two opposite points upon its surface remain stationary, which are called the *poles.* The line connecting these points—also stationary—passes through the center, and is called the *axis.* Points upon the surface describe circles around the axis, which are called *parallels.* These increase according to their distance from the poles—the middle and greatest parallel being called the *equator.* Circles drawn upon the earth's surface through the poles, and cutting the parallels and equator at right angles (Introd. § 17), are called *meridian circles.* Half of each meridian circle, extending from pole to pole, is called a *meridian.* (*Man.* 7.)

27. *Planes of the Equator, Parallels, etc.*—We may form a good idea of a plane (Introd. § 7) by imagining a perfectly smooth and "straight" sheet of glass, with indefinite length and breadth, but without appreciable thickness. Such planes, we will conceive to divide

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CHAP. I.—25. How many square miles in the earth's surface? What furnishes us with starting points and lines, from which to measure the surface? 26. Name these points and lines, and explain how they are obtained. 27. *Illustrate planes. What is meant by the "plane of the equator," etc.? How far beyond the earth's surface does the plane of the equator extend?*

the earth in different parts. The plane C, cutting the surface through the equator, is called the *plane of the equator*,—through a parallel, D, the *plane of a parallel*, etc.

The figure shows the planes extending to but a short distance beyond the earth's surface. There is, however, no limit to their extent; the plane of the equator, for example, not only divides the earth, but it may be conceived as dividing *all space*, into two equal parts.

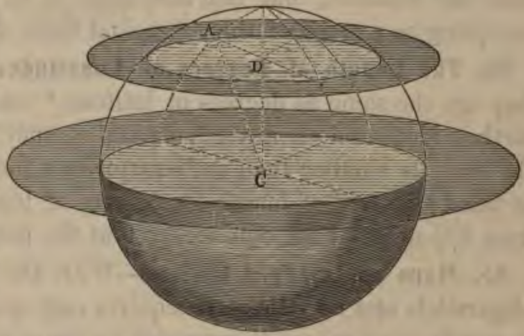

FIG. 6. *Planes of the Equator and a Parallel.*

28. Latitude is distance from the equator, measured in degrees on a meridian, either north or south. Thus, the north pole is in latitude 90° north; the tropic of Capricorn is in latitude 23½° south.

29. Longitude is distance from a certain fixed meridian, measured in degrees on a parallel, either east or west.

30. *The Prime, or First, Meridian* is the fixed meridian from which longitude is measured, as latitude is measured from the equator. If there were a certain meridian naturally distinguished from all the rest, as the equator is distinguished from all the other parallels, of course it would be selected as the prime meridian. But there is no such meridian; all are of the same length, and we can distinguish them only by important places through which they pass. Thus, the meridian which passes through Washington, is called the meridian of Washington; and Americans sometimes measure from this as the prime meridian. More commonly, however, Americans use the English prime meridian, which passes through Greenwich. Other important nations measure from their own capitals.

31. Having the Latitude and Longitude of a Place given, we know its exact position upon the earth's surface, and can find it upon a map or globe as readily as we can find a house by its street and number, or a soldier by his company and regiment. (*Man.* 8.)

28. What is latitude? 29. Longitude? 30. The prime, or first, meridian? What distinguishes the equator from all other parallels? What distinguishes the first meridian from other meridians? How is the first meridian selected? 31. Of what advantage is a knowledge of the latitude and longitude of places?

32. *Significance of the Names.*—We can measure but 90° from the equator, while we may measure 180° from the first meridian. Hence, the former distance is called latitude (*breadth*), and the latter, longitude (*length*).

33. The Length of corresponding Degrees of Latitude is the same, on whichever meridian they be measured. Near the poles, they are longer than near the equator; but the difference is so slight as to be unimportant, excepting as a proof of the spheroidal form of the earth (§ 23).

34. The Length of Degrees of Longitude.—Measured on the equator, they are the same as degrees of latitude,* viz., $\frac{1}{360}$ the circumference of the earth. Measured on any other parallel, they are less, since the parallel circle itself is smaller than the equator or a meridian circle. Hence, there is no fixed standard of length for degrees of longitude, which vary all the way from 69⅛ miles at the equator, to 0 at the poles.

35. Maps and mapped Globes.—With the aid of this admirable system of parallels and meridians, it requires only accuracy and unwearied industry to enable geographers to represent on maps and globes the comparative position, extent, and outline, or form, of the continents, islands, countries, seas, etc., which variegate the immense surface. Should they attempt the task without the aid of these guiding lines, they would soon find themselves lost in the most hopeless confusion.

Exercises.

1. Can a place be farther north than the north pole? How many degrees of north latitude are there?

2. When a ship is sailing directly away from the equator,—in other words, when it is "making latitude,"—is it sailing along a parallel, or meridian?

3. Then, is latitude measured on a parallel, or meridian?

4. When a ship is sailing directly away from the prime meridian, is it sailing along a parallel, or meridian?

5. Then, is longitude measured on a parallel, or meridian?

6. A certain vessel was wrecked in lat. 10° south; long. 10° west from Greenwich. Near what land was it?

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32. What is the meaning of the words "latitude" and "longitude," and why are they used? 33. How do degrees of latitude compare with one another, in length? 34. Degrees of longitude? 35. What great object is accomplished by this system of measurement?

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* There is a *slight* difference, however, on account of the earth's spheroidal form.

7. In what longitude is New York city, measuring from Greenwich? From Washington? From Paris?
8. Is the 180th degree of longitude east, or west, longitude?
9. In what longitude are the poles?
10. If a vessel should sail directly north from the equator, steering in the same direction until it has passed over a space equal to 100 degrees, in what latitude would it be?
11. A vessel sails due west from the meridian of Greenwich, over 200 degrees of the parallel; in what longitude is it from Greenwich?
12. How far apart may two points be, and yet be in the same latitude?
13. How far apart may two points be, and yet be in the same longitude?
14. How many meridians may be drawn through a parallel?
15. How many parallels may be drawn through a meridian?
16. How many miles in a degree of latitude?
17. What is the length, in miles, of a degree of longitude measured on the equator?
18. About what part of a mile does a degree of longitude measure on the parallel 7 miles distant from the pole? (*Consider the space within the circle flat, and multiply the diameter of the circle by* $3\frac{1}{7}$, *to obtain its approximate circumference.*)

CHAPTER II.

ZONES.

36. Meaning of "Zone."—If the space between two parallel circles upon the surface of a sphere be distinguished from the rest of the surface, it will present the appearance of a *belt* encircling the sphere; hence the name *zone* (belt).

37. Number and Names of the Zones.—The surface of the earth is divided, by four parallel circles, into five zones, viz., *North Frigid*, *North Temperate*, *Torrid*, *South Temperate*, and *South Frigid*. The four dividing circles are the *Tropics* and *Polar Circles*.

CHAP. II.—36. Explain the word "zone." 37. Name the zones and the dividing circles.

THE ZONES ARE NATURAL DIVISIONS OF THE EARTH'S SURFACE, MADE BY CERTAIN RAYS OF THE SUN.

38. The Torrid Zone.—The sun's vertical rays do not always fall upon the equator. Sometimes they fall upon the parallel 23½° north of the equator—the tropic of Cancer; at other times, upon the parallel 23½° south of the equator—the tropic of Capricorn; and, in the meantime, upon every circle between these two. But they never fall farther north or south than the tropics. (These northward and southward movements of the sun will be described more fully, and their causes explained, in a future chapter.) Now, the solar light and heat are the most intense where the vertical rays fall; consequently these rays distinguish a zone of the earth's surface, 47° in breadth and divided from the rest of the surface by the tropics. This is called the *torrid zone*[1]. From its lying between the tropics, whatever pertains to it is often called *tropical*; *e. g.*, tropical fruits, birds, animals, etc. (*Man.* 9.)

39. The Frigid Zones.—For the same reason that the vertical, or hottest, rays of the sun do not always fall upon the equator, the most oblique, or *coldest*, rays do not always fall at the poles. And, as the vertical rays range 23½° from the equator, so the most oblique rays range 23½° from the poles. Consequently, these rays mark off two sections of the earth's surface, each 47° in diameter and divided from the rest by the arctic and antarctic circles. These are called the *frigid zones.*[2] (*Man.* 10.)

40. The Temperate Zones.—Between the torrid and the frigid, lie the *temperate*, zones; upon which neither the vertical nor the most oblique rays of the sun fall—that is, neither the hottest nor the coldest rays; hence their name. (*Man.* 11.)

Ex. What is the breadth of the temperate zones?

41. The Difference between the Climate of the Torrid and that of the Frigid Zones is so great that, if animals belonging to one should be carried

38. ARE THE ZONES NATURAL, OR ARTIFICIAL, DIVISIONS? Explain how the sun marks off the torrid zone. 39. The frigid zones. 40. The temperate zones? 41. How does the climate of the torrid zone compare with that of the frigid zones?

(1) Torrid; *torridus*, hot.
(2) Frigid; *frigidus*, cold.

to the other, they would soon perish; and, while the rankest luxuriance of vegetation grows in one, there are but a few hardy shrubs and mosses to vary the eternal snows of the other.

42. *The Reasons for this great Difference* may be easily understood from Figs. 12 and 13, pp. 40 and 41, and the paragraphs relating to them.

43. *Gradual Decrease in Temperature from the Equator to the Poles.*—Representations of the earth, with the zones painted upon its surface, imply very abrupt changes at the dividing circles; but, of course, no more sudden change would actually be experienced in crossing these dividing circles, than in crossing any other parallel.

CHAPTER III.

DIMENSIONS, DISTANCES, AND DENSITIES.

44. The Circumference of the Earth (Introd. § 23) is, in round numbers, 25,000 miles.

45. The Diameter is a little less than one-third of the circumference, or about 8,000 miles.

46. *More accurately,* the polar diameter is 7,899 miles, while the equatorial diameter is 26½ miles greater, or 7,925½ miles.

Multiplying these numbers by 3.1416 (Introd. § 34—II), we have the circumference of a meridian circle, or polar circumference, 24,815 miles; and the equatorial circumference, 24,898 miles.

47. The Earth's Distance from the Sun varies slightly during the year, the greatest distance (*Aphelion*, § 101) being estimated at 93,000,000 miles; and the least (*Perihelion*), at 90,000,000 miles. The average, or mean, distance is, therefore, 91,500,000 miles.

48. The Moon's Distance from the Earth varies during the month, the

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42. Explain the difference. 43. *Do the tropics and polar circles imply abrupt differences in climate?*

CHAP. III.—44. What is the circumference of the earth, in round numbers? 45. The diameter? 46. *Give the measurements more accurately.* 47. What is the earth's distance from the sun? 48. The moon's distance from the earth?

greatest distance (*Apogee*, § 146) being about 252,000 miles; and the least (*Perigee*), about 226,000 miles. Its mean distance is, therefore, about 239,-000 miles.

For the sake of comparing the earth's magnitude with that of other heavenly bodies, and with space, other distances and magnitudes are annexed.

49. The Distances of the other known Planets (Introd. § 37) from the sun, vary from about one-third, to thirty times that of the earth.

Ex. About how many miles from the sun is the nearest planet? The most distant planet?

50. The Distances of the Fixed Stars are so great that they are utterly beyond our comprehension. The very nearest of them is about 200,000 times more distant from us than we are from the sun. But even this vast distance is small, compared with that of the great multitude of the stars.

51. The Sun's Diameter is 853,000 miles, or nearly 108 times as great as that of the earth. The sun, therefore, is a body 108 times as long, 108 times as wide, and 108 times as thick, as the earth, making it (108 × 108 × 108) more than 1,250,000 times as large as the earth.

52. The Moon's Diameter is 2,158 miles, or a little more than one-fourth that of the earth.

53. The Diameters of the other known Planets vary from a little less than one-half, to more than eleven times that of the earth.

54. Density of the Earth.—The earth weighs about 5½ times as much as it would weigh if composed entirely of water. We say, therefore, that its density is 5½.

55. Densities of the Sun, Moon, and other Planets—The sun weighs about 1½ times as much as if it were composed of water; in other words, its density is 1½. The moon's density is 3½. The densities of the other planets vary from 1 to 7.

Ex. 1. Which is the most *solid*,—the sun, earth, or moon?

2. How many times more solid than the moon is the earth.

56. The Earth in Space.—The earth seems to us an immense body, especially when we consider that the loftiest chains of mountains only serve to "roughen" its surface in a slight degree. Yet, huge as it seems, we see, from the numbers given above, that it is one of the very smallest of the

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For what purpose are other distances and magnitudes given? 49. *How do the distances of the other planets from the sun, compare with that of the earth?* 50. *The fixed stars?* 51. *What is the sun's diameter?* 52. *The moon's diameter?* 53. *How do the diameters of the other planets compare with that of the earth?* 54. What is the earth's density? 55. *What are the densities of the sun, moon, and other planets?* 56. How does the magnitude of the earth compare with that of objects upon its surface? With that of other heavenly bodies?

bodies that roll in space. In fact, the whole solar system (Introd. § 38) taken together, is but a mere atom, when compared with the Universe.

As the student of Botany regards some insignificant plant as only an individual of an innumerable species, so let us regard the planet upon which we live, as only a sample—rather small than otherwise—of countless myriads, made on the same general plan. (*Man.* 12.)

Exercises.

1. What is the exact distance from the north pole to the center of the earth? (§ 46.)
2. What is the exact distance from the equator to the center?
3. What is the distance from the north pole to the equator, measured over the surface? Measured in a straight line under the surface? (Introd. § 34—I.)
4. What is the length, in miles, of a degree of the equator? (Introd. § 13.)
5. What is the length, in miles, of a degree of the parallel circle passing through D (Fig. 6), 3,000 miles from the center? (Hypothenuse, AC, 4,000 miles, and perpendicular, CD, 3,000 miles given to find the base, AD, which is the *radius* of the parallel circle required.)
6. What is the area of the surface of the earth? (Introd. § 34—III.)
7. How many cubic miles in the earth? (Introd. § 34—IV.)
8. What is the circumference of the sun? (§ 51.)
9. What is the circumference of the moon? (§ 52.) The area of the moon's surface?

CHAPTER IV.

HOW DISTANCES AND MAGNITUDES ARE MEASURED.

(The details of astronomical measurements cannot be understood without some knowledge of Trigonometry; still a few hints may be given in a familiar manner, which shall enable the pupil to understand the *general principle* employed. Younger classes, however, had better omit this chapter altogether.)

57. Measurement of the Earth.—The accurate measurement of the earth is a matter of the utmost importance; since from it are measured the magnitudes and distances of all other bodies. An error of 1 mile in its diameter, for instance, involves an error of more than 12,000 miles in the sun's

How does the solar system compare with the Universe? How may we regard the earth? CHAP. IV.—57. What is said of the measurement of the earth?

distance. Accordingly, no pains have been spared to obtain its exact dimensions. Several different methods have been employed, of which two of the simplest are briefly mentioned.

58. *First Method.*—The amount of curvature of a small portion of the surface may be measured (§ 7), and from this arc the whole circumference may be calculated.

Ex. A peak of the Andes, 4 miles high, is just visible on the Pacific Ocean at the distance of 178¼ miles. Now, in order that a line, 178¼ miles in length, should curve downward 4 miles from a perfectly straight line, it must form an arc of a circle equal to 2.58 degrees. How many miles in 360 degrees, or the whole circumference? Ans. 24,872+miles.

59. *Second Method.*—The number of miles in a degree of latitude may be determined, which, multiplied by 360, will give the circumference.

The length of a degree of latitude may be found as follows:

The north star remains apparently motionless in the sky, excepting as we move toward it or from it. If we sail toward it, over one degree of the earth's circumference, it will seem to ascend one degree toward the zenith; if we sail one degree from it, it will seem to descend a corresponding distance toward the northern horizon. It is found that, in order to cause the north star to move apparently one degree in the sky, a ship must sail about 69⅛ miles directly north or south. Hence, 69⅛ miles must be one degree of the earth's circumference. Multiplying this by 360 we have the circumference, 24,900 miles.

Measurement of Distances.

60. Parallax is the apparent difference in the position of an object, as viewed from different points. Thus, if you stand in one part of a room, an object in the middle of the room is seen as if it were against a certain window; whereas, if you move a few steps, it may be seen as if it were against a door. In this case, the distance between the window and door is the *parallax* of the object, as seen from your two positions.

61. *Measuring the Distance of a near Object from its Parallax.*—Hold a finger before the eyes, and look steadily at a wall or window beyond. The finger will appear in two different positions against the wall or window. Close the right eye, and it will appear at A; close the left, and it will appear at B. The line AB is the *parallax* of the finger, or its apparent difference of position as viewed from two points—the eyes.

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58. Describe the first method. *Example.* 59. The second method. How may a degree of latitude be measured? 60. *What is Parallax? Illustrate.* 61. *How may the distance of a near object be measured? As parallax increases, does distance increase, or diminish?*

If the parallax, AB, is comparatively great, the finger is very near the eyes; if small, the finger is comparatively distant. Thus, even if you could estimate the distance of the finger in no other way, you could estimate it from its parallax (knowing the distance between the eyes), which grows smaller as the finger becomes more distant. Remember, therefore, that *the smaller the parallax of an object is, the greater is its distance.*

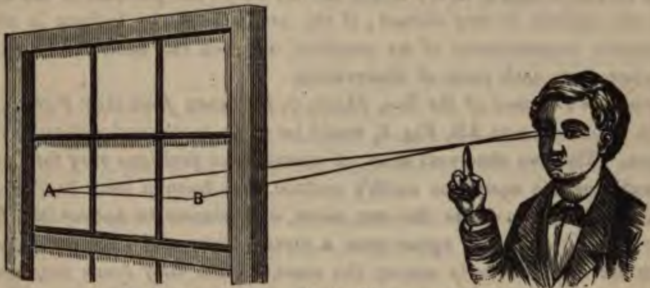

FIG. 7. *Parallax of an Object near the Eyes.*

62 *Measuring the Distance of a distant Object from its Parallax.*—Fig. 8 represents two men measuring the parallax of a balloon.

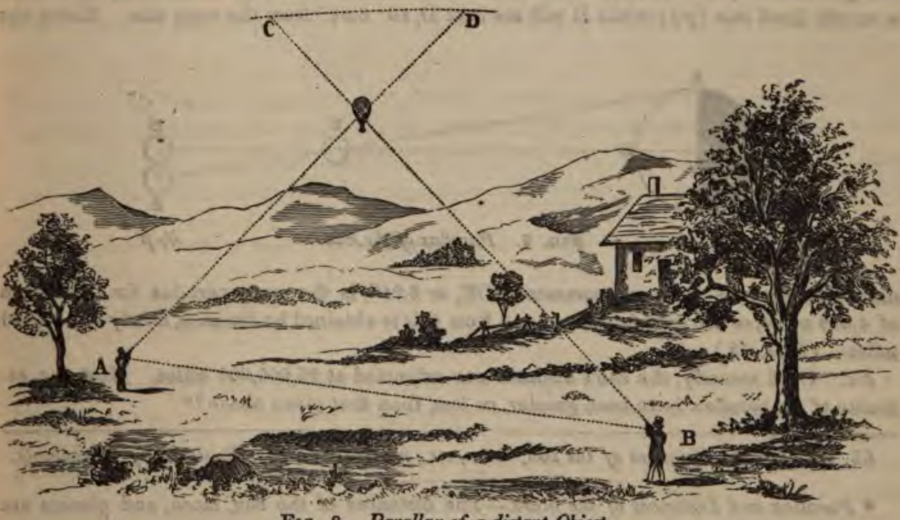

FIG. 8. *Parallax of a distant Object.*

62. *With Fig. 8, explain the method of measuring the distance of a more distant object from its parallax.*

The distance between our eyes is not sufficiently great to enable us to measure the parallax of a distant object; we must, therefore, take two points of observation at a greater distance apart. The men, in the picture, have measured a *base line*, AB, and are observing the balloon from the ends of this line. They see it at two different points against the sky, C and D, just as the two eyes see the finger in two different positions against the window. A sees the balloon at D, and B sees it at C; hence the arc CD is the parallax of the balloon. If it is very small, the balloon is very distant; if the arc is large, the balloon is comparatively near. By accurate measurement of its parallax, the men can ascertain its exact distance, in feet and inches, from each point of observation.

63. *Measuring the Distance of the Sun, Moon, and Planets from their Parallax.*—In these cases, so short a base line as AB, Fig. 8, would be of no more service than the distance between the eyes. The two observers must, of course, take positions very far apart. If they stand at opposite points upon the earth's surface, they have a base line of nearly 8,000 miles; which is sufficient to cause the sun, moon, and planets to appear in different places to each observer. If, now, they agree upon a certain time, and each notes the exact position in which he sees the body among the stars,—when they come together again and "compare notes," they have the same means for measuring the distances of the sun, etc., that the two eyes have for measuring the distance of the finger, or the two men represented in Fig. 8, have for measuring that of the balloon.

64. Thus, if A and B, Fig. 9, take positions about 4,000 miles apart (measured in the straight line AC), A will see the center of the sun at E, a certain distance—say 10°—from a certain fixed star *(p)*; while B will see it at D, 10° 8.94″ from the same star. Hence the

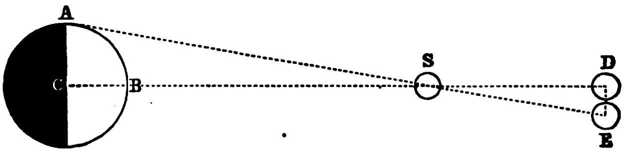

FIG. 9. *Parallax of the Sun.*

difference between these measurements, DE, or 8.94″, is the sun's parallax for a base line of 4,000 miles, or the earth's radius; and from this is obtained its distance, nearly 91,500,000 miles. (*Man.* 13.)

Ex. Until recently, the sun's distance was estimated at 95,000,000 miles. Must the estimate of its parallax have been greater, or less, than that given above?*

63. *How are the distances of the sun, moon, etc., measured?* 64. *Illustrate by an example.*

* *Parallax and Distances of the Stars.*—The distances of the sun, moon, and planets are easily obtained in the manner which has been explained. But, when we try to obtain the distances of the fixed stars in this way, we find that the whole diameter of the earth is of no more use as a base line, than the line AB in Fig. 8, or even the distance between the

65. Measuring the Diameters of the Sun, Moon, etc.—Knowing the distances of these bodies, we can estimate their size. Place a circular piece of paper before one eye at such a distance that it will exactly cover the disk of the body. Now, a circle twice as far off would have to be of twice the diameter in order to fill the same space in the eye; one a hundred times as distant would have to be of one hundred times the diameter, and one as many times as distant as the body, would have to be as many times as great in diameter, that is, of the same diameter as the heavenly body itself.*

Ex. If a paper disk, 1 inch in diameter, be pasted on a window-pane in view of the full moon, a spectator will have to withdraw $9\frac{7}{27}$ feet from the paper disk in order that it may just cover the moon. Required, the moon's diameter.

Ans. The moon's distance being 240,000 miles, or 136,857,600 times greater than that of the paper disk, its diameter must also be the same number of times greater than that of the paper disk. $136{,}857{,}600 \times 1 \text{ inch} = 2{,}160$ miles.

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65. *How may we measure the sizes of the sun, moon, etc.? Can the stars be measured in this way? (Note at bottom.)*

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eyes. So extremely distant is even the nearest of the stars, that it is seen in precisely the same direction, viewed from opposite sides of the earth, just as a tree in the horizon seems in the same place, viewed by either eye. Therefore, we cannot hope to know any thing of the real distances of the stars, unless we can find a longer base line. Such a line has been found—no less than 23,000 times the earth's diameter! viz., *the diameter of the earth's orbit around the sun.* Even with this immense distance between the two points of observation, only a very few of the nearest stars give any parallax—and that so exceedingly slight, that the nicest observation is necessary to detect it. By this means, the distance of the nearest star (Alpha Centauri) has been estimated at about 20,000,000,000,000 miles! (*Man.* 14.)

* The stars cannot be measured in this way, since none of them have any apparent diameter whatever. We judge of their magnitudes simply from their known distance and *brilliancy.*

SECTION THIRD.—THE SUN'S RAYS.

CHAPTER I.

THE SUN'S RAYS AND THE EARTH'S ATMOSPHERE.

66. Light is the Means of Sight, although itself invisible.—We often speak of "seeing light;" but it is not light that we see, but the various *objects* which send light to our eyes. Light is not a substance;—it is only a *means* which, by affecting our eyes, enables us to see substances.* If there were no substance in view, we should be surrounded by darkness, even though the space around us were filled with rays of light.

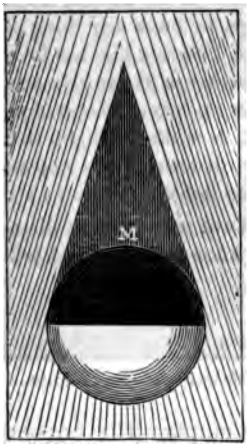

FIG. 10.

67. *Examples showing that we do not see Light.*—1. If we stand before a brilliantly lighted window upon a dark evening, the rays from within will pour upon us in a flood, and the space between us and the window will seem bright with the light. But, if we move to a corner of the building so that the window itself shall not be within the range of vision, the space in front of it—if the air is perfectly clear—will seem as dark as if the window were unlighted; in other words, we can not see the *rays* pouring out into that space. If, however, some *substance* move into the space, as a passing carriage or even a cloud of mist, it will be suddenly lighted up. The *rays* will enable us to see the *substance*.

2. At midnight, when the sun is far below the horizon, his rays must, of course, *shoot up* on all sides of the earth, as shown in Fig. 10; and, if these rays *could be seen*, they would present the appearance of a dazzling shower pouring up from the horizon on all sides, causing the night to be nearly as bright as the day. At midnight, however, we see no evidence of the sun's rays, unless there is some *substance* above us, like the moon or planets, to receive the rays and throw them back to us.

CHAP. I.—66. What is light? 67. *Prove that light is invisible. Of what is light a form? (Note at bottom.)*

* Light is one of the forms of *natural force*. The other principal forms are *heat* and *attraction*. All these are supposed to be transmitted through a subtle, extremely rare medium filling space, called the *ether*.

68. Air* in large Quantities is visible, and of a pale blue color. We look upward in the day-time, and see what seems to us an immense flood of pure "light." Of what is this vast illuminated ocean composed—whose upper surface seems a shell of pale blue? It cannot be *light* that we see, for we have shown light to be invisible. Plainly, then, it must be some *substance* lighted by the sun's rays, just as a cloud of mist would be lighted by a candle.

That substance is the *air*. If it were removed, the "flood of light" would disappear, and we should see nothing above us, even at noon, but a black, measureless abyss, with the sun glaring in the midst, and the stars and moon as plainly visible as they are now at night.

69. *Why we do not realize that the Air is visible.*—This is because we have nothing more transparent than itself, with which to contrast it. If a great ball of air could be suspended in empty space beyond our atmosphere, we should see it shining at night, like a planet.

FIG 11. *The Earth's Atmosphere illuminated by the Sun's Rays.*

70. *Fig.* 11 shows the air thus lighted by the sun's rays. The *halo*, repre-

68. Why is the sky so bright by day? What would be the appearance of the heavens, if it were not for the atmosphere? 69. Why do we not realize that the air is visible? 70. Explain Fig. 11.

* Including all the various gases, etc., which the atmosphere contains.

sented as half surrounding the earth, may be regarded as a picture of the "flood of light" which we see above us in the day-time, and which would disappear if the air were removed. If we could ascend above this, we should see the black, starry space surrounding the atmosphere, as is proved by those who make balloon ascensions or climb lofty mountains. These men describe the sky growing darker and darker, as they leave more and more of the atmosphere below them, until the stars become visible even at noon-day.

Fig. 10 is an example of the manner in which light is usually represented. It will be understood, however, that only the *directions* of the rays are shown by the straight lines, as the directions of the equator, ecliptic, etc., are shown by curved lines.

71. Heat.—The principle explained and illustrated above, applies also to rays of *heat*. They produce no effect until they meet some *substance*, upon which to operate. Consequently, in the empty space beyond the atmosphere it is intensely *cold*, as well as dark.

72. Refraction.—In entering any transparent substance, as air, water, glass, etc., *obliquely*, rays of light are *refracted*, that is, *bent* from the straight course they would otherwise pursue; and the denser the substance, the more the rays are refracted. We may illustrate this by viewing objects through a piece of glass, held with its surface oblique to the direction in which we are looking. The fact, that the rays coming from the objects to our eyes are bent by the glass, is shown by the changed positions in which the objects appear. In the same way, rays of light from the heavenly bodies, entering the earth's atmosphere obliquely to its surface, are very slightly refracted; and we see the bodies from which they come—excepting those in the zenith—a *little higher* than they really are. For this reason, they appear above the horizon before they have really risen, and after they have really set.

73. The Speed of Light is about 184,000 miles a second. It requires, therefore, a little more than 8 minutes for a ray of light to reach us from the sun. (p. 99, note at bottom.)

EXERCISES.

1. When rays of light enter a room in which the air is clear, you see the bright aperture where they enter, and the bright spot on the wall or floor where they strike; but do you see any evidence of the rays between these two points? (§ 66.)

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70. How may it be proved to be a correct representation of the earth in space? *How is light passing through space, usually represented? To what may the lines representing the rays, be compared?* 71. What is said of rays of heat? 72. *Describe refraction. Illustrate. What is the effect of refraction upon the apparent positions of the heavenly bodies?* 73. What is the speed of light? How long does it take a ray of light to reach us from the sun?

2. Suppose the air through which the rays pass, be suddenly filled with dust (as by the striking together of two black-board erasers) will the rays seem to become visible? What do we see, in this case—the rays themselves, or merely particles of dust, brilliantly lighted?

3. When the sun is in the eastern horizon, why is the western sky so bright? How would it appear if there were no atmosphere? (§ 68.)

4. The moon has little or no atmosphere; what must be the appearance of the sky, as seen from the moon?

5. How long does it take light to reach us from the moon? (§ 48 and § 73.)

6. How long does it take light to reach us from the nearest fixed star? (§ 50.) If, then, a star had been blotted out of existence years ago, might its light still continue to shine upon us?

CHAPTER II.

GRADUAL CHANGES IN LIGHT AND HEAT DURING THE DAY AND YEAR.

74. Twilight is the gentle sunlight that plays around us before sunrise and after sunset. It is nothing more than the gray border of the "flood of light," described in the preceding chapter (§ 68), and represented in Fig. 11.

75. ***How Twilight is produced.***—Long before the sun's direct rays reach us, they shine upon the upper regions of the air in the east, and produce the first "gray streaks of dawn."* We see this brightened air in the distance, just as we see the tops of distant mountains lighted up before sunrise, and after sunset. As the sun rises higher and higher toward the horizon, more and more of the air above our heads becomes lighted up, until, at the appointed instant, his broad disk bursts into view.

76. The Day.—Even then, we have not the full light of day. We may gaze upon the very face of the sun, and scarcely feel his warmth. As he

CHAP. II.—74. What is twilight? 75. Explain its cause. 76. Is the change from the morning twilight to daylight, a sudden change?

* Twilight begins when the sun is about 18° below the horizon.

makes his sublime ascent, he becomes more and more powerful, until he reaches his culmination, after which his power as gradually diminishes, till the second twilight has faded away into the darkness of night.

77. The Year presents similar gradual changes in light and heat, and the changes of both the day and the year are due to the same cause, viz: differences in the direction of the sun's rays.

Two Reasons why Differences in the Direction of the Sun's Rays make Differences in their Power.

78. *First:* The *more slanting* the rays, the *greater the surface* over which they are scattered; and, hence, the *less intense their power.*

Fig. 12 represents three sheafs, or bundles, of the sun's rays, striking the earth at three different periods of the day. At noon the rays are vertical, and fall upon the surface between C and D. In the middle of the afternoon they are inclined, and are spread over a greater surface, DE. At sunset the lower side of the sheaf just touches the surface, while most of the rays themselves are lost in the atmosphere beyond.

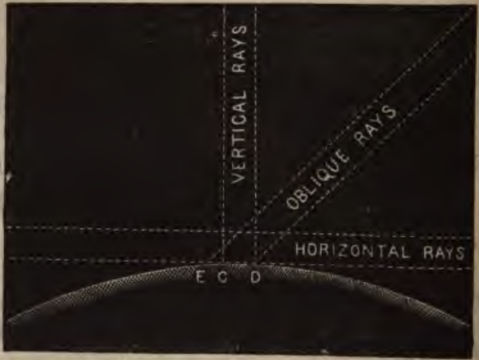

Fig. 12. *Dispersion of Rays over Surface.*

79. *Second:* The *more slanting* the rays, the *more air* they must pass through; and, therefore, *the more they are interrupted and absorbed.*

We have already learned that the air is not perfectly transparent; it interrupts the light as glass interrupts it, though not in so great a degree. A clear pane of glass *seems* to admit as much light as an open space of equal extent; but, if it were a hundred times as thick, it would admit scarcely any light. So, if the air were sufficiently increased in quantity, we should be left in utter darkness, as if we were at the bottom of the ocean. When we look at the sun in the horizon, we see him through an immense mass of air (p. 37, note at bottom); hence he sometimes appears of a dull red

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77. In what respect does the year resemble the day? To what are the changes of both due? 78. Give the first reason for this. *Explain Fig.* 12. 79. The second reason.

, as if seen through smoked
.

In Fig. 13, SBA represents a noon
' sunlight, and S′ DA, one at sunrise
set.* If the curved line BD repre-
the outside of the atmosphere, 50
† above the surface of the earth, it is
it that the rays must penetrate
gh very much more air, when the sun
the horizon than when he is over-

If the line BA is 50 miles, and AC,
miles, what is the length of the line
hat is, through how many times more
ist a *horizontal* ray pass, than a *verti-*
? (Introd. § 34—I.) *Ans.* 12.68

FIG. 13. *Interruption of Rays by the Atmosphere.*

Explain Fig. 13. *Example.*

efraction (§ 72) would curve the ray AD slightly downward, thus causing it to pass
gh a still greater quantity of atmosphere than represented.

fty miles is the height usually assigned to the atmosphere, although it probably
nes off, in a state of extreme rarity, many hundred miles beyond this limit—gradually
ing off," as it were, into nothingness. Its *great mass*, however, is within 8 or 10 miles
earth's surface; the more elevated portions comparing with the lower very much as
por of the ocean compares with the ocean itself.

SECTION FOURTH.—THE REAL AND APPARENT MOTIONS.

CHAPTER I.

THE EARTH'S MOTIONS.—THE DAILY MOTION.

81. The Earth performs two Motions.—It rotates (Introd. § 29) once in twenty-four hours, and revolves around the sun once a year.

82. *The Motions are permanent.*—Nothing made by man will continue in motion indefinitely, unless new force is repeatedly applied to it. A watch will stop, unless it is wound at regular intervals, and even then it will finally wear out. But the earth never wears, and will never stop, unless some great change takes place in nature, to produce such a result.

83. *What keeps the Earth moving?*—Every one knows that a top will spin much longer on a smooth surface than on a rough one, and that it will spin scarcely a second of time under water. Having been set in motion, the length of time during which it will continue moving, depends, *first*, on the amount of friction between the peg of the top and the surface on which it spins; *secondly*, on the density of the medium in which it spins. Suppose the top to be spinning in a perfectly empty space without friction or any other resistance to overcome; how long will it continue in motion?—a day? a year? What will then cause it to stop? It will require as much force to destroy its motion as was required in the first place to produce it, and, unless that force is applied, it will continue spinning forever.

The earth is like a huge top in precisely similar circumstances. It rotates in empty space, and there is no friction between its surface and any external surface, as there is between the peg of the top and the floor. But

CHAP. I.—81. What are the earth's motions? 82. What great difference between the motions of the earth and those produced by human art? 83. Why does a spinning top finally stop? How long would it spin, if its motion were not resisted? What force is re- quired to destroy a motion? Explain why the earth's motions continue undiminished.

does not the air resist the motion of the earth, as it resists that of the top? By no means; the air is a *part* of the earth—a thin covering—and, like the ocean, is carried around with it. (*Man.* 15.)

The same principle applies to the earth's motion around the sun as to its rotation. It continues undiminished, simply because there is nothing to *resist* it.

84. The Effects of the Earth's Rotation:

1. Alternation of day and night (§ 85).
2. Determination of an axis, equator, etc. (§ 26).
3. Flattening at the poles (§ 18).
4. Apparent rotation of the heavens in the opposite direction (§ 91).
5. Ebb and flow of the tides twice a day (§ 154).

85. The Alternation of Day and Night.—As the sun shines on only one-half the earth's surface at a time, the other half must be in darkness. If there were no motion, one half would be in constant day, and the other half in constant night; but the rotation of the earth brings each half, in turn, into the light and shade. (*Man.* 16.)

86. *The Circle of Illumination, or Terminator*, is the line which divides the light from the dark portion of the earth or any other planet. The moon's *terminator* is plainly seen at any time between new moon and full moon. (See Fig. 34, p. 74.)

Exercises.

1. When it is noon at Boston, where, on the same parallel, is it sunrise? Sunset? Midnight? *

2. When it is sunrise at London, where, on the same parallel, is it noon? Sunset? Midnight?

3. Over how much of a meridian is it noon at the same instant?

4. Over how much of a parallel is it noon at the same instant?

5. How many miles an hour does a body at the equator move around the earth's axis?

6. If a man or animal should perform this rapid motion *through* the air, would he be likely to feel the resistance? *Ans.* The effect would be very much greater than that of the most violent hurricane.

Does the earth move through the air? 84. What are the effects of the earth's rotation? 85. Show how day and night are produced. 86. What is the terminator?

* In this and the following question the sun is supposed to be directly over the equator.

7. Then, does the earth move through the air, or does the air move with the earth?
8. What is the rate of motion at the poles?
9. Is the rate of motion on the parallel 10 miles from the poles, very rapid, or slow?

CHAPTER II.

PROOFS OF THE EARTH'S ROTATION. — APPARENT DAILY MOTION OF THE HEAVENS.

87. Belief of the Ancients.—The ancients generally supposed that the earth is perfectly motionless; and that the sun, moon, and stars perform daily revolutions around it.

88. *Insensible Motion often causes a similar Delusion.*—The motion of a balloon through the air is so extremely gentle—however rapid it may be—that, if one closes his eyes or looks only at the sky, it seems motionless; and, upon looking downward, the sensation is strong that the earth is *falling away* from the balloon, rather than that the balloon is rising above the earth. Although we are totally insensible of the earth's motion, yet we feel that it would be almost as absurd for us to regard the earth as stationary and the heavens in motion around it, as for the aëronaut to regard his balloon as fixed and the earth descending below it. But we are not obliged to content ourselves with mere probabilities;—the earth's rotation is proved to a *positive certainty.*

Proofs of the Earth's Rotation.

89. First Proof.—When a grindstone is rotating rapidly, it will throw drops of water in the direction in which it is rotating; if, for example, its upper surface is moving toward the east, it will throw the drops eastward. *The earth does precisely the same thing.* A stone dropped from the top of a high tower, always falls a *little east* of a vertical line; that is, it is *thrown a little eastward* by the earth's rotation.

Chap. II.—87. How did the ancients explain day and night, etc.? 88. What is said of insensible motion? What is said of the supposition that the earth is motionless? 89. How does a body falling from a great height prove the earth's rotation?

90. Second Proof.—*Foucault's Experiment.*—Attach a pendulum to a large globe so that the point of suspension will be over its pole; let the pendulum end in a sharp point which will make a scratch upon the globe at each vibration; let the pendulum swing, and slowly rotate the globe under it. You will observe that, notwithstanding the rotation, the pendulum will constantly swing toward the same two points in the room, that is, in the same plane. The consequence will be a star-shaped figure scratched upon the globe by the pendulum point, which will make a different line at each vibration. A similar experiment has been tried upon the earth itself, with a like result. At the equator, where the relation between the plane of vibration and the earth's surface is not changed by the rotation, the pendulum marks only one line; but the nearer it is to the pole, the nearer the figure which it describes approaches the star-shaped figure represented in the engraving, which could not be the case if the earth did not rotate.

FIG. 14. *Proof of the Earth's Rotation.*

APPARENT DAILY MOTION OF THE HEAVENS.

91. Different Rates of apparent Motion of the Stars, etc.—Among the effects of the earth's daily motion (§ 84), is the apparent daily rotation of the starry sphere (with the sun, moon, etc.) in the opposite direction, from east to west. The same principles apply to this apparent motion that apply to the rotation of any sphere, viz., the poles (the north star,* and the opposite point in the heavens) remain stationary, merely turning upon themselves as upon pivots, while the rate of apparent motion increases according to the distance from the poles, being swiftest at the *celestial equator*, or *equinoctial*, which lies over the earth's equator (*Man.* 31), as the celestial poles stand over the earth's poles. Stars near the pole star seem to move in small circles around it every twenty-four hours, precisely as icebergs are car-

90. *Describe Foucault's experiment.* 91. What causes the heavenly bodies to describe daily circles? In what part of the heavens do the stars seem to move at the slowest rate? At the quickest rate? Why?

* The north star is at a very slight distance ($1\frac{1}{3}°$) from the true north pole of the heavens. Consequently, it seems to describe a minute daily circle around it.

ried by the earth's rotation around the north pole, only in the opposite direction; stars farther off, describe larger circles—those over the equator describing the largest of all.

FIG. 15.—*Apparent Daily Motion of the Heavens.*

92. How to observe the apparent Rotation of the Heavens.—Most people know where to look among the stars for the "*Dipper*," a part of the constellation *Ursa Major*, or *Great Bear*. It is represented in Fig. 15, ABD. The two stars A and B are called "*pointers*," because they seem to *point* to the pole star P. The circles in the figure show the apparent revolution of the stars, or in other words, the rotation of the celestial sphere in the direction of the arrows, from east to west.

Now, on some clear evening, carefully observe the relative positions of the Dipper and some other cluster, as *Cassiopeia*, M, which resembles an irregular W in form. The book can easily be held so that the stars in the figure shall correspond in position with those in the sky. Observe also the positions of certain bright stars overhead and near the eastern and western horizon. Compare their positions again about three hours afterward. The north star will not appear to have moved; the Dipper will have moved through $\frac{3}{24}$, or $\frac{1}{8}$, of the whole circle, and the pointers will be at E and F. All the other stars will also have moved through $\frac{1}{8}$ of their circles—those that were in the eastern horizon having ascended, those that were overhead having descended toward the west, and those that were in the western horizon having set.

93. *Circles of Perpetual Apparition and Occultation.*—The stars within the heavily marked circle G, never pass below the horizon, day or night. This circle is, therefore, called the circle of *Perpetual Apparition (appearance)*. The south pole of the heavens is as far below the horizon as the north pole is above it. There must, therefore, be a circle around the

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92. *How may we easily observe the apparent rotation of the heavens?* 93. *Define and explain circles of perpetual apparition and occultation.*

pole corresponding to G, in which the stars never "rise." This is called the circle of *tual Occultation (concealment).* Both these circles increase as we move toward the and diminish as we move from it.

Daily Motion of the Heavens, as seen ifferent Points of the Earth's Surface. s. 16 and 17 represent the earth in nter of the hollow sphere of the ns; PP′ represents the poles of the ns directly over the poles of the ; and EQ, *the celestial equator*, or *ctial*, over the earth's equator.

m the North Pole.—If we should at N, our horizon would be the equi-l; the north star would be over- and the other stars, with the sun, and planets, would seem to move les around us—*aa′*, *bb′*, *cc′*, *etc.*

m the Equator.—If we should at E or W (hold the page so that W shall be uppermost), the north ould be in the northern horizon; he other stars, sun, moon, etc. seem to move in circles perpen-r to the horizon.

m any Point between the Equator ole.—If we should stand between quator and north pole, as at X, 7, HO would represent our hori-bove which the north star, P, be seen at a distance correspond- our distance from the equator; he other stars, sun, moon, etc. seem to move in circles oblique horizon—*aa,′ bb,′ cc,′* etc.

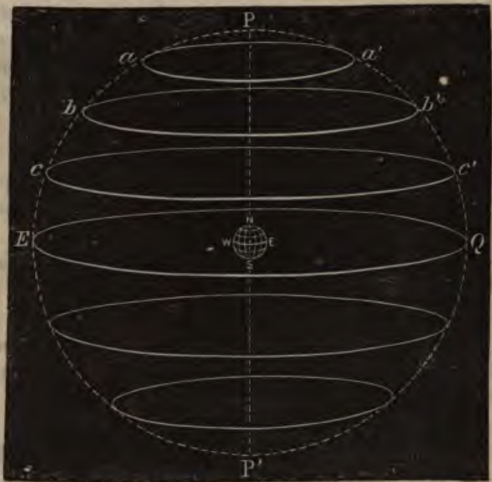

FIG. 16. *Parallel Sphere.*

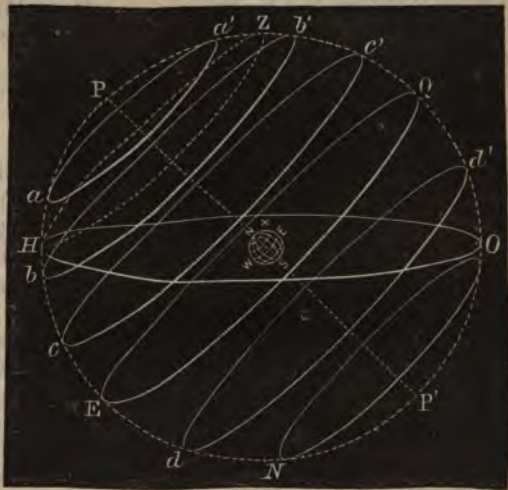

FIG. 17. *Oblique Sphere.*

1. What points represent the and nadir to an observer at N? To an observer at E? To observers at the poles, what is rcle of perpetual apparition. To an observer at X?

What do Figs. 16 *and* 17 *represent? Describe the celestial movements, etc., as seen from th pole. From the equator. From a point between the equator and* poles. Examples.

95. Length of Time during which a Heavenly Body moves above and below the Horizon.—It is evident that, to an observer at one of the poles (N, Fig. 16), a body above the horizon—whether sun, moon, or star—remains above during the whole twenty-four hours: to an observer at the equator, the sun, moon, and stars are half the time above, and half the time below: to an observer at a point between the north pole and equator (X, Fig. 17), a body over the equator is half the time above and half the time below the horizon, a body north of the equator is longer above than below, and a body south of the equator is longer below than above: to an observer between the south pole and equator, the last two conditions are reversed. Hence, when the sun is over the equator, the day and night are equal, when he is north of the equator our day is the longer, and when he is south of the equator our day is the shorter.

96. The Distance of the North Star above the Horizon at any Place, measures its North Latitude.—If we are at the equator, we see the north star *in* the horizon, showing that our latitude is 0. If we are at the north pole, we see the north star in the zenith, or 90° above the horizon, showing that our latitude is 90°. If we are midway between the north pole and equator (X, Fig. 17), we see the north star midway between the zenith and the horizon, showing that our latitude is 45°, etc.

Exercises.

1. How many miles an hour would the sun have to move, if the earth were motionless, in order to produce a day and night every 24 hours? (§ 47, and § 34—II of Introd.) Is it reasonable to suppose that the sun performs this rapid motion?

2. If the earth turned on its axis from east to west, in what direction would the heavens seem to move?

3. Would there be anything of importance to distinguish the north star from the rest of the stars, if the earth did not rotate? (§ 91.) Would *any* of the stars appear to move? *Ans.* They would not.

4. How far south must we go in order to see the south pole of the heavens?

5. The crew of a ship see the north star above the horizon, one-fifth of the distance from the horizon to the zenith; in what latitude are they? (§ 96.)

6. When the sun is over the equator, which are longer, our days or nights? (§ 95.)

7. When the sun is north of the equator, which are longer? When the sun is south of the equator?

8. At a time when the sun is known to be over the equator, a ship's crew see it, at noon, 10° south of the zenith; in what latitude are they?

9. Then, may latitude be determined from the sun, as well as from the north star?

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95. *To an observer at a pole, during what part of the 24 hours do different heavenly bodies remain above the horizon? To observers in other places? Explain the varying length of day and night.* 96. *How may a traveler, north of the equator, always know his exact latitude?*

CHAPTER III.

THE EARTH'S YEARLY MOTION.—DIRECTION OF THE TWO MOTIONS.

97. What makes the Earth move around the Sun?—If a stone be attached to an elastic cord and swung around the hand, not only will the earth's revolution around the sun be illustrated, but also the *two forces which produce the revolution.* The force exerted by the hand tends to throw the stone in a direction *from* the hand; and, if that force should cease, the elastic cord would pull the stone *toward* the hand. The cord prevents the stone from moving from the hand; and, if the cord should break, the stone would fly off in a straight line, in the direction in which it happened to be moving when the cord parted.

If, for example, the cord should part when the stone reached A, the latter would fly off in the line AB; at C, it would take the direction CD, etc.* But, so long as the cord remains unbroken—since the stone cannot move either toward or from the hand—it must take a direction *between*, or in a curve around the hand.

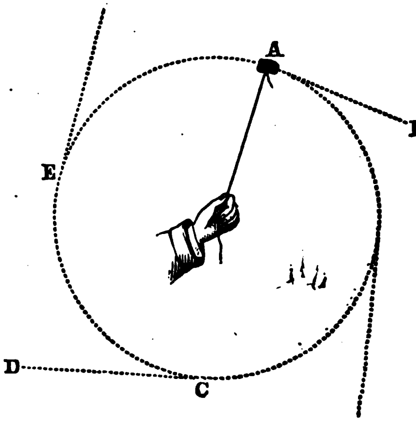

FIG. 18. *Centripetal and Centrifugal Forces.*

In like manner, the force which was first communicated to the earth tends to cause it to move onward in a straight line, while the sun's attraction tends to draw it to the sun; but the two opposite forces are so adjusted that it moves in a nearly circular pathway around the sun, which is called its *orbit.*

98. *Centrifugal and centripetal Force.*—The force which tends to move a

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CHAP. III.—97. How may the earth's yearly motion, with its cause, be illustrated?

* The lines AB and CD are *tangents* to the circle ACE.

body in a straight line, is called *centrifugal*[1]; that which tends to draw it from this straight line into a curve, is called *centripetal*[2].

Ex. 1. Which of these forces prevents the stone (Fig. 18) from being drawn to the hand?
2. Which prevents the stone from flying from the hand?
3. Which prevents the earth from falling to the sun?
4. Which prevents the earth from flying off into space?

99. Form of the Earth's Orbit.—If the two forces, centrifugal and centripetal, were exactly balanced, and no disturbances were made by the attraction of other planets, the earth's orbit would be a perfect circle; but such is not the case; its real form is that of an *ellipse*.

100. *How an Ellipse may be drawn.*—A thread is attached to two pins, which are fixed at a greater or less distance apart. A pencil is then moved along the thread, keeping it stretched, until a curve is described entirely around the pins. If the pins are together, the curve is a circle; as they are separated, the curve becomes more and more elongated, forming an ellipse of greater or less *eccentricity*,[3] according to the distance between the pins. The points occupied by the pins are called *foci* (singular *focus*) of the ellipse. The center of the sun is in one of the foci of the earth's elliptical orbit. (*Man.* 18.)

FIG. 19.

101. *Perihelion and Aphelion.*—The earth's orbit being an ellipse, our distance from the sun varies slightly at different times. When the earth is nearest the sun, it is said to be in *perihelion*[4]; when most distant, in *aphelion*.[5] (*Man.* 19.)

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98. Define centrifugal and centripetal force. *Examples.* 99. Under what conditions would the earth's orbit be a circle? What is its form? 100. *How may an ellipse be drawn? What are the foci?* 101. When is the earth in perihelion? When in aphelion?

(1) Centrifugal; *centrum*, and *fugio*, I flee from.
(2) Centripetal; *centrum*, center, and *peto*, I seek.
(3) Eccentricity (*Ex*, from, and *centrum*, the center), the distance from the center, where the dotted lines (Fig. 19) cross, to either focus. The longest diameter of an ellipse is called its *major axis*; the shortest, its *minor, or conjugate, axis*.
(4) Perihelion; *peri*, near, and *helion*, the sun.
(5) Aphelion; *apo*, from, and *helion*, the sun.

102. *Amount of the Eccentricity of the Earth's Orbit.*—The perihelion distance is 90,000,000 miles; the aphelion distance is 93,000,000 miles. The difference, 3,000,000 miles, is comparatively very small, so that the orbit is very nearly circular. In fact, if an accurate figure of it should be drawn upon paper, the nicest eye could scarcely distinguish it from a perfect circle.

103. *Rate of Motion in different Parts of the Orbit.*—The earth moves a *very little faster* in perihelion than in aphelion. (*Man.* 20.)

DIRECTION OF THE EARTH'S MOTIONS.

104. Both are in the same Direction, viz., from west to east. The relation of the two motions may be fixed in the memory by associating them with those of a rolling ball or carriage wheel, which may be said to rotate in the *same direction* in which it advances. (*Man.* 17.)

105. *What is meant by "from West to East."*—It is very easy to understand the propriety of these words, so far as they apply to the *daily* motion. Indeed, we can even *see* the earth rolling eastward. Look at the eastern horizon when the sun is rising. Impress it strongly upon your mind that the sun is really motionless, and you will have no difficulty in seeing the eastern horizon *sinking* below the sun, and yourself carried eastward *toward* the sun. At sunset, you will see the western horizon *rising* above the sun, and yourself carried eastward *from* the sun.

But, when we try to connect the direction "eastward" with the earth's *yearly* motion, we find that our ordinary idea of the word aids us very little; for two observers upon opposite sides of the earth are carried in *exactly opposite* directions, although, according to the preceding paragraph, both are moving toward the "east." The points of the compass applied to space, are quite different from the same applied to the earth's surface. In the latter case, north is toward the north pole of the earth, and south is toward the south pole; in the former, north is toward the north star, south in the opposite direction, and east and west are in the direction of *circles* in space facing the north star.

If, for example, a clock should be placed so that the pivot upon which its hands turn should point to the north star,—then the pivot would point north and south, as these directions lie in space; and the hands themselves would move from east to west, no less on the lower than the upper part of the dial. If you could stand in space, with the north star above your head, a planet moving in front of you, from your right to your left, would be moving "from west to east"; and this is the direction in which you would see the earth and other planets

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102. *How much does the form of the earth's orbit differ from a perfect circle?* 103. Is the rate of the earth's motion uniform? 104. What are the directions of the earth's daily and yearly motions? 105. *Is it difficult to understand the application of the words "west" and "east" to the daily motion? Illustrate their obscurity as applied to the yearly motion. How is the difficulty solved?*

moving around you, if you could stand where the sun is, in the position described above —that is, with your head toward the north star.

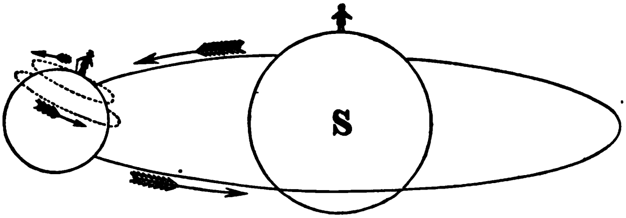

FIG. 20. *Direction of the Earth's Rotation and Revolution.*

106. *Fig.* 20 shows the directions in which an observer upon the north pole of the earth, and another upon the sun, would see the earth performing its daily and yearly motions. The north star must be imagined at an immense distance above the north pole of the earth. It will be seen from this that the direction of the earth's yearly motion, instead of being *exactly* eastward, is a little *north* of east during half the revolution, and a little south of east during the other half.

107. Principal Effects of the Earth's Revolution around the Sun:—1. The apparent yearly revolution of the sun around the earth, through the twelve Signs of the Zodiac.

2. The Change of Seasons. This is a combined result of the yearly motion, and the inclination and unchanging direction of the earth's axis.

EXERCISES.

1. Suppose the sun were suddenly destroyed, how would the earth move? (§ 97.)

2. What would be the result if the earth's revolution around the sun should entirely cease? (§ 97.)

3. Considering the earth's orbit a perfect circle, with a radius of 91,500,000 miles, what is its circumference? *Ans.* Nearly 600,000,000 miles.

4. Then, about how many miles per day does the earth move in its orbit?

5. When do we move the more rapidly in our journey around the sun, at noon, or midnight?*

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106. *Explain Fig.* 20. 107. What are the principal effects of the earth's yearly motion?

* This question may be answered very easily with the aid of the apparatus. It will be seen that, at midnight, the two motions of the earth carry us in the *same direction*, and, therefore, our real motion is the *sum* of the two; while, at noon, the directions of the two motions are opposite, and, therefore, our true motion is their *difference*.

6. Suppose you could stand motionless above the north pole of the earth, would you see the earth rotating under you from right to left, or from left to right? (See Fig. 20, p. 52.)

7. Suppose you stood motionless above the south pole, in which direction would you see the earth rotating under you?

CHAPTER IV.

HOW WE MAY WATCH THE EARTH'S YEARLY REVOLUTION AROUND THE SUN.

108. Cause of the Sun's apparent Yearly Motion.—As the earth's real motion upon its axis causes the whole heavens to seem to move around the earth once a day, so the earth's real motion around the sun causes the sun to seem to move around the earth once a year (§ 107).

109. *In what the Sun's apparent Yearly motion consists.*—The apparent daily revolution of the sun around the earth has nothing to do with its apparent yearly revolution; the latter consists in its *apparent changes of position among the stars.*

Now, the stars, on account of their immense distances, seem as immovably fixed in the immense hollow sphere that surrounds us, as if they were silver nails in a blue ceiling; and they appear to turn with that hollow sphere once a day, as the nails would move with the ceiling if the latter should perform a rotation.

But the sun (although, in reality, a star) does not appear thus fixed. If we could see the (other) stars in the day time, we should see it creeping very slowly past them—from west to east. If it appears beside the star *a*, Fig. 23, at sunset to-day, it will appear at *b*, a little east of that star at sunset to-morrow, at which time *a* will be just below the horizon. The next day at sunset the sun will appear still farther east, so that the point *b* will

CHAP. IV.—108. What is the cause of each of the sun's apparent motions? 109. Does the sun's apparent yearly motion consist in his rising and setting? In what *does* it consist? Do not the stars rise and set, as well as the sun and moon? Why, then, are they called *fixed* stars? Is not the sun really a star? Is it a *fixed* star? Why not? (§ 108.) Describe its apparent yearly motion, with the aid of Fig. 23.

then be below the horizon—and so on, until, in 365¼ days, the sun will appear to have made an entire circuit around the heavens, and to have returned to its starting point beside *a*. (*Man.* 25.)

110. *We may observe the Sun's apparent Motion among the Stars as accurately as if they were visible in the Daytime.*—1. If we observe what stars are just above the western horizon as soon after sunset as they become visible (the uppermost stars in Fig. 23, for example), we shall find, at the same time to morrow, that these stars have descended somewhat, which will show that the sun has approached them, that is, that he has moved a little *eastward.*

2. Since the sun is on the meridian upon the other side of the earth at midnight, certain stars on our meridian must be *exactly opposite* the sun; and, as *different* stars appear on our meridian at midnight night after night, the sun must be opposite different stars at different times. (*Man.* 24.)

For example, when the earth is at *a*, Fig. 21, we see the stars at C on the meridian at midnight, and we know that the sun is on the other side of the earth, opposite these stars, appearing to observers upon the opposite side of the earth, in that part of the heavens denoted by A.

Three months afterward, when the earth has moved to *b*, we shall see the stars at D on the meridian at midnight, and shall know that the sun is opposite them.

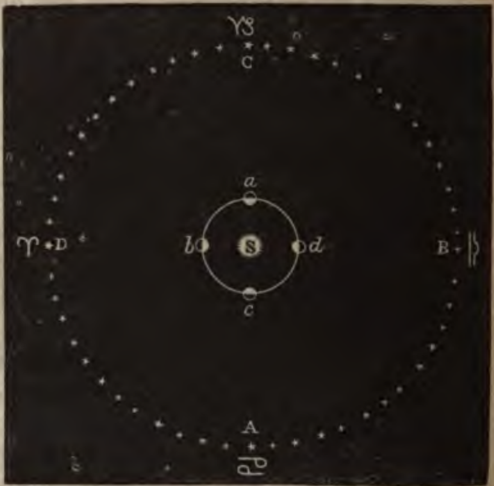

FIG. 21. *The Earth's real, and the Sun's apparent Yearly Revolution.*

Ex. 1. To what point will the earth have moved three months later?

2. What stars shall we then see on the meridian at midnight?

3. Among what stars would the sun seem to be at this time, if we could see the stars by daylight?

110. What prevents our observing the sun's motion among the stars, by day? Describe *two ways in* which we may observe the motion. *Examples.*

4. As the earth moves from *c* to *d*, the sun seems at the same time to move past what stars?

5. Would the sun seem to make this movement if the earth remained motionless?

6. If the sun seems to move entirely around the heavens in a year, through what part of the circle does he seem to move in a day? *Ans.* Nearly 1 degree.

111. Other Heavenly Bodies move among the Stars.—The moon and planets also change their positions among the stars from day to day, moving generally in the same direction in which the sun moves, viz., from west to east. But here a most important distinction must be made;—the moon and planets *really* move, while the sun's motion is only *apparent.*

FIG. 22. *Zodiac encircling the Heavens.*

112. The Zodiac is that great zone, or belt, of the heavens, within which the sun, moon, and planets are seen to move. It is 16° in width, 8° each side of the ecliptic (§ 113). The stars within the zodiac are divided into 12 constellations, from which the 12 "Signs of the Zodiac" are named. (*Man.* 22.)

113. The Ecliptic is the earth's real yearly path, or sun's apparent yearly

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111. *What is said of other heavenly bodies? What important distinction must be made?* 112. Describe the zodiac. 113. The ecliptic.

path through the heavens. It lies along the middle of the zodiac, as seen in Figs. 22 and 23.* (*Man.* 23.)

114. The Signs of the Zodiac, with their Symbols.—†

1.	Aries,	*the Ram,*	♈.
2.	Taurus,	*the Bull,*	♉.
3.	Gemini,	*the Twins,*	♊.
4.	Cancer,	*the Crab,*	♋.
5.	Leo,	*the Lion,*	♌.
6.	Virgo,	*the Virgin,*	♍.
7.	Libra,	*the Balance,*	♎.
8.	Scorpio,	*the Scorpion,*	♏.
9.	Sagittarius,	*the Archer,*	♐.
10.	Capricornus,	*the Goat,*	♑.
11.	Aquarius,	*the Waterbearer,*	♒.
12.	Pisces,	*the Fishes,*	♓.

115. *Fig.* 23 represents the sun setting, with the stars visible—as they would be if it were not for the atmosphere (§ 68). The space within the two oblique lines on either side of the sun, represents a portion of the zodiac, with the ecliptic running along the middle. Nearly the whole of the sign Cancer (♋) is seen, with a portion of Leo (♌), and a corner of Gemini (♊).

On the 21st of June, we see the sun entering the sign Cancer. When he sets the next day, he will have advanced nearly one degree *into* Cancer,—having moved along the ecliptic to *b*, as was shown in § 108,—leaving the star *a* below the horizon. A month later, he will have moved along the ecliptic to Leo (♌). At sunset at this time, the bright stars seen in the engraving will be below the horizon, and those above, or east of them, will have taken

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114. *Name the signs of the zodiac, and write their symbols.* 115. *Explain Fig.* 23.

* That the earth's real path and the sun's apparent path among the stars are one and the same line, may be seen from Fig. 21. ABCD represents that circle of stars reaching around the earth and sun, through which the ecliptic cuts. While the earth really moves around past these stars, the sun seems to move past the same stars—only at the opposite part of the circle. Thus, when the earth at *a* is really passing the stars at C, the sun seems to pass the stars at A. Six months afterward, when the earth at *c* is passing the stars at A, the sun seems to pass the stars at C.

Distinguish carefully between the sun's *daily* and *yearly* path. In the former, the sun moves westward *with* the stars,—in the latter he moves eastward *past* them.

Ex. In which case does he describe the ecliptic?

† Each sign is about 30° west of the constellation of the same name—a result of the precession of the equinoxes. (Supplement III.)

their place. During the next month the sun will enter Virgo (♍), the next sign east of Leo.

FIG. 23. *Sunset, June 21st.—Sun entering Cancer.**

Ex. 1. What sign will he enter after passing through Virgo? (§ 114.)

2. In how many months will he return to Caneer?

116. Solar and Sidereal Day.—*Questions*:—

1. Suppose the sun and a certain star, *a*, Fig. 23, set at the same instant to-day; which will set first to-morrow?

Examples. 116. *Questions.*

* The brightest star in the engraving, a little north of the equinoctial, is *Procyon*, in the *Little Dog.*

A little right of the center is seen the bright star *Pollux*, one of the *Twins;* close by it, just north (at the right) of the zodiac, is *Castor*, the other Twin. The bodies of the Twins extend westward (downward) toward the sun.

In the lower right hand corner is *Menkalinan*, in the shoulder of the *Wagoner;* while three faint stars above form *Herschel's Telescope.*

Three stars in the form of a triangle, near the symbol ♌, surround the *Bee-hive.*

2. What will be the difference in their time of setting?

Ans. The sun, being $\frac{1}{365}$ of the whole circle around the heavens *east* of the star, will set $\frac{1}{365}$ of 24 hours, or nearly 4 minutes, later. (*Man.* 26.)

Hence, the time between sunset and sunset is about 4 minutes longer than that between star-set and star-set. The former is called a *solar* day, and the latter, a *sidereal* day. Each is divided into 24 equal parts, called in the one case, solar hours, and in the other, sidereal hours.

3. How many solar hours and minutes are there in a sidereal day? *Ans.* 23 h. 56 m. (nearly).

4. How many sidereal days in 365 solar days? *Ans.* 366 (nearly).

5. How many times does the earth turn on its axis to produce 365 solar days?

Ans. As the stars are fixed in the sky, the earth must turn just once on its axis between two settings of the same star, that is, in one sidereal day; consequently, it must turn 366 times to produce 365 solar days. (Qu, 4.)

6. If the earth did not move around the sun, would the sun seem to move among the stars? Then, would there be any difference between the solar and sidereal day?

7. If we could not see the stars, what should we know of the earth's yearly revolution?

Ans. We might *suppose* its existence from the changing seasons; although these might be produced by a pendulum-like motion of the earth's axis, which would change the direction of the solar rays (§ 130) —the earth, in the meantime, remaining stationary.*

A Field Experiment.

An agreeable and highly profitable variation of the previous demonstrations is as follows:†

Select a tree in a broad, open field to represent the sun, and station yourself at a little distance from it to represent the earth. Now, as the stars are inconceivably more distant than the sun, they must be represented by comparatively distant objects, as, for example, those in the horizon. Suppose, therefore, the tree-tops, church-spires, hills, etc. in the horizon to be stars in the zodiac surrounding the sun and earth, like the circle in Fig. 21.

Now, in the first place, imitate the daily motion of the earth *alone* by turning slowly on your heels without moving from your place. All objects in sight seem to revolve around you in the direction opposite to that in which you are turning, and not only this, but all seem to perform their revolutions in *the same time;* the objects in the horizon seem to describe their *great* circles as quickly as the tree describes its *small* circle. Moreover, you always see the tree against the same point in the horizon. From this you infer that, if the earth only rotated on its axis without moving from its place, the sun and stars would perform their apparent daily revolutions around the earth in precisely the same time, and that the sun would always be seen among the same stars.

* During the precession of the equinoxes (Supplement III), the earth's axis performs a gyration which, of itself, would produce a change of seasons. There is a slight periodical change, also, in the degree of inclination of the earth's axis. In fact, there are numerous instances of *oscillation* known to every astronomer.

† This will scarcely be necessary, however, to classes provided with the Apparatus.

Now imitate the yearly motion taking place alone, by moving in a circle around the tree without turning on your heels, that is, always facing in the same direction, as, for example, south or east.

Ah! now a great difference is seen. The tree seems to revolve around you in the same direction in which you revolve around the tree, only at the opposite point in the circle, and, if you watch it against the horizon, you will see it moving past the tree-tops, church-spires, etc., completing its apparent revolution in the same time that you complete your real revolution. Observe also that it appears on one side of you, passes in front, and disappears on the other side, while you are performing *half* your revolution, and remains out of sight during the other half. These appearances teach you that, if the earth performed its revolution around the sun without rotating on its axis, the sun would rise, perform a six months' journey through the constellations, and then disappear for the remaining six months of the year. You notice also that the tree-tops, etc. in the horizon, do not appear to change their positions in the least perceptible degree during your revolution around the tree, but that you see them in the same direction from all sides of your orbit. This illustrates to you the significance of the word *fixed* as applied to the stars, which, were it not for the daily rotation of the earth, would always remain fixed in the same points of the sky, as far as ordinary vision could determine. A nice instrument would enable you to distinguish a slight *parallax*, or change of position, in some of the objects in the horizon as viewed from opposite points of your orbit around the tree; but a much more delicate instrument would be required to detect the parallax of the stars as seen from opposite points of the earth's orbit.

Having imitated the daily and yearly motions separately, now imitate them together, as the earth performs them. Of course, the two classes of *effects* will be combined, and will correspond exactly with those which you observe in the heavens. Every time you turn round to the tree *(sun)*, you find it has made a little advance in the horizon *(ecliptic)*, until it has described the whole circle.

EXERCISES.

1. What distinguishes the constellations of the zodiac from the other constellations in the sky? (§ 112.)

2. If the sun is exactly on the meridian at this moment, where will it be in exactly twenty-four hours? Where will it be in exactly one sidereal day? (§ 116.)

3. In what direction is the earth's daily motion? The apparent daily motion of the heavens? The apparent daily motion of the sun? The apparent yearly motion of the sun?

4. As you ride in the cars, what objects seem to move past you more rapidly—those which are near, or those which are more distant? Then, if you had no other means of judging of distance, which would you conclude to be farther off—those which seem to move slowly, or those which seem to move rapidly? What would you conclude to be the distance of hill-tops, which seem not to move past you at all?

5. The earth is carrying you along in its orbit, as the car carries you along over the rails (having, at the same time, another motion which the car has not, viz., rotation); you see the sun and stars in the zodiac, as you see various objects in the landscape from the car window. The sun seems to change its place as you move—the stars do not; what may you conclude from this alone, in regard to their comparative distances?

SECTION FIFTH.—THE INCLINATION OF THE EARTH'S AXIS.

CHAPTER I.

WHAT IS MEANT BY THE INCLINATION OF THE AXIS?

117. Plane of the Earth's Orbit, or Plane of the Ecliptic.—This can be understood best by an illustration. Suppose two spheres, representing the earth and sun, to be half immersed in a smooth sheet of water, the former floating around the latter in an elliptical orbit, shown by the dark line (Fig. 24). The smooth surface of the water represents a plane passing through the

FIG. 24.—*Illustration of the Plane of the Ecliptic.**

earth's orbit. Now, if you can imagine the water removed, and the spheres still continuing their motions undisturbed, the exact space which the surface of the water occupied will present to your mind a very accurate idea of the plane of the earth's orbit, or plane of the ecliptic. It must be imagined as cutting through the centers of both sun and earth, and extending to an indefinite distance beyond the earth's orbit. To an observer standing upon the

CHAP. I.—117. Illustrate the plane of the ecliptic, or plane of the earth's orbit, with the aid of Fig. 24 How must it be imagined?

* In the apparatus (Fig. B), the earth is represented as cutting through a similar plane in its movement around he sun.

ball representing the earth, the other ball would seem to move around him in the surface of the water; hence the plane of the earth's orbit is also the plane of the sun's apparent path, or ecliptic. (*Man.* 28.)

118. *Meaning of "Ecliptic."*—The moon revolves around the earth in an orbit which crosses the plane of the ecliptic at a small angle, so that it is half the time on one side, and the other half on the other side of this plane. The smallest ball in the engraving represents the moon thus revolving around the earth and crossing the plane of the ecliptic in two points *(nodes)*. Now, no *eclipse*(§149), either of the sun or moon, can take place excepting when he moon is crossing the plane, as is evident from the figure. Hence, the plane of the earth's orbit takes its other name—*plane of the ecliptic* (or *eclipses*).

119. The Earth's Axis is inclined to the Plane of the Ecliptic.—We observe that the earth's axis, as represented in Fig. 24, does not stand upright, or perpendicular, in the plane of the ecliptic; and that the equator is, therefore, cut by the plane in two points.

120. *The Amount of the Inclination of the Earth's Axis* to a perpendicular to the plane of the ecliptic, is 23½ degrees, or 66½ degrees to the plane itself.

Let N E S W represent the earth, and the line S′ S′ the plane of the ecliptic with its edge turned exactly toward us. If the axis were perpendicular to the ecliptic, it would be represented by the line PR (Introd. § 18), and TT′ would represent the equator lying exactly in the plane, or, as the usual expression is, "coinciding with it." If, now, we take the north pole, P, and move it 23½° to the point N, we shall have it in its true position. While we are doing this, we move every other point in the whole circumference an equal distance; hence the point R moves to S, and

Fig. 25.—*Inclination of the Earth's Axis.*

118. *Why is the plane of the earth's orbit called also the plane of the ecliptic?* 119. What is the attitude of the earth's axis in the plane of the ecliptic? What, therefore, is the attitude of the equator in the same? 120. How much is the earth's axis inclined? *Explain Fig.* 25.

*23° 27′ 24″

the points TT′ of the equator move to W and E—each $23\frac{1}{2}°$ from the plane of the ecliptic.

Ex. 1. How many degrees in the arc PN? The angle PCN, then, is an angle of how many degrees? (Introd. § 16.)

2. What arc measures the angle NCT′? How many degrees, then, in the angle?

3. The angle WCT is an angle of how many degrees?

4. What angle does the equator make with the plane of the ecliptic? With the perpendicular to the plane of the ecliptic?

121. *Relation of the Tropics to the Equator and Plane of the Ecliptic.*—The tropics of Cancer and Capricorn are denoted by the circles on either side of the equator in Fig. 24, and by the lines OT′ and TF in Fig. 25. They are, each, $23\frac{1}{2}°$ from the equator, and we see that the plane of the ecliptic cuts across from one to the other.

A circle, called the "Ecliptic," is generally drawn upon terrestrial globes across the equator from tropic to tropic. A similar circle is made by the surface of the water around the globe represented in Fig. 24, which explains the meaning of the former. The circle drawn upon the globe must rotate with the globe, however, whereas it *should* be stationary, like the circle made by the surface of the water. (*Man.* 29.)

122. The Earth's Axis constantly points in the same Direction during the yearly Revolution, viz., toward the North Star. (*See note at bottom of p.* 45.)—If it were not for this fact, we should not always see the north star, summer and winter, at the same distance above the northern horizon.

This unchanging direction of the earth's axis is exhibited in Fig. 28, p. 66. The north star must be imagined at an immense distance in the direction in which the various lines denoting the earth's axis, point; so that, although the lines, being parallel, are really directed to four different points, yet, like the parallel lines of a railway track, they seem to meet in a single point in the distance. (*Man.* 30.)

123. How we know that the Earth's Axis is inclined to the Plane of the Ecliptic.—The fact of the inclination is proved, and its amount measured, by the sun's apparent movements north and south of the equator. treated of in the following chapter.

Examples. 121. How are the tropics situated with reference to the equator and plane of the ecliptic? *What is said of the "Ecliptic" on terrestrial globes?* 122. How does the earth's axis point? Explain how the earth's motion in its orbit does not prevent its axis from always pointing to the same spot in the sky. 123. How do we know that the earth's axis is inclined to the plane of the ecliptic?

CHAPTER II.

THE SUN'S DECLINATIONS, OR APPARENT MOVEMENTS NORTH AND SOUTH OF THE EQUATOR.

124. Cause of the Sun's Declinations.—Every one is familiar with the expressions:—"The sun is crossing the line;" "The sun is coming north, and we shall soon have warm weather;" "The sun is going south, and the days are growing shorter;" etc. Like the two apparent movements of the sun already described, this is not due to any change in the sun's real position, but must come home to the earth itself. The cause is threefold:

1. The inclination of the earth's axis.
2. The unchanging direction of the axis.
3. The earth's revolution around the sun.

As a result of these three conditions, the north pole of the earth is sometimes inclined directly *toward* the sun, at which time the sun is over the tropic of Cancer, $23\frac{1}{2}°$ north of the equator. At other times, the north pole is inclined directly *from* the sun, at which time the sun is over the tropic of Capricorn, $23\frac{1}{2}°$ south of the equator. During the intermediate times, the sun must be somewhere between these circles—being directly over the equator, or "crossing the line," twice a year.

125. *The Sun's Declinations appear in a Spiral Path winding around the Sky, like the Threads of a Screw.*—This is in consequence of the earth's two motions going on together. On the 20th of March, we see the sun rise at E, Fig. 26, describe the arc through A, and set at C. This arc is directly over the equator, and is, therefore, the *equinoctial.* Day and night are now of equal length, and the period is, for this reason, styled the *spring*, or *vernal*,[1] *equinox.*[2] On the next day, the sun describes a circle a little north of

CHAP. II.—WHAT IS MEANT BY THE SUN'S DECLINATIONS? 124. Explain their cause. Between what two circles are they included? 125. Does the sun describe the same path, from his rising to his setting, day after day? Describe his daily paths, as illustrated in Fig. 26.

(1) Vernal; *ver*, spring.

(2) Equinox; *equa*, equal, and *nox*, night.

the equinoctial; the next, still farther north; and so on, until, on the 21st of June, he has reached the limit of his northern declination. The circle which he describes on this day, S, is directly over the tropic[1] of Cancer, 23½° north of the equator, or equinoctial. For a few days he seems to describe nearly the same circle, whence the name of the period—*summer solstice.*[2]

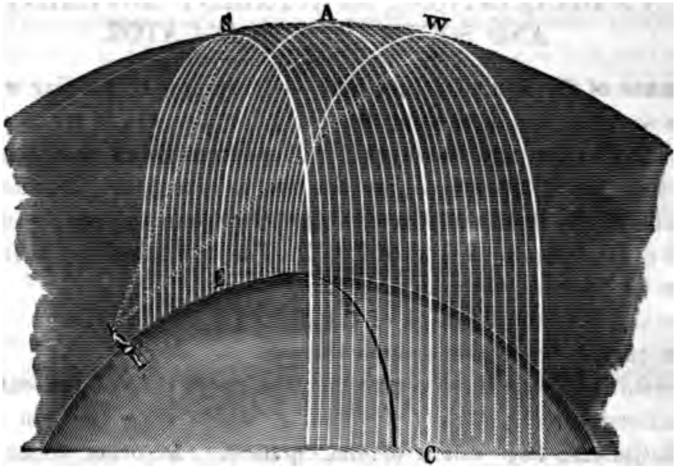

FIG. 26. *Sun's apparent Motion on different Days during the Year, north and south of the Equator.*

From the summer solstice, the sun describes his circles farther and farther south each day, until, on the 23d of September, he again describes the equinoctial, or "line," EAC. Day and night are again equal—the *autumnal equinox.* Thence, he continues still southward till the 21st of December, when he describes the circle W over the tropic of Capricorn. This is the limit of his southern declination,—the *winter solstice,*—from which, after a few days, he begins his return northward. (*Man.* 34.)

On what days is he over the equator? What celestial circle does he describe on these days? On what days is he most distant from the equator? Over what circle is he on these days? What is the name of each of these four periods?

(1) Tropic; from a Greek word signifying a *turning point.*

(2) Solstice; *sol,* the sun, and *sto,* I stand—because the sun seems to stand still at a solstice. Very similar to the solstice, is the highest point to which a pendulum swings, when it *stops* an instant before it begins its descent.

126. In Fig. 23 (p. 57), the oblique line at the left of the zodiac represents a portion of the equinoctial. The sun is seen at his greatest distance north,—the summer solstice,—and, as he moves along the ecliptic toward ♌ day after day, it is plain that he will constantly approach the equinoctial, until he will cross it at the autumnal equinox.

127. *Tropics named from the Signs Cancer and Capricornus.*—On the 21st of June, when the sun is over the tropic of Cancer, he is also entering the sign Cancer: on the 21st of December, when he is over the tropic of Capricorn, he is entering the sign Capricornus.

128. The Effects of the Sun's northern and southern Declinations:

1. The Change of Seasons.
2. The Variation in the length of Day and Night.

CHAPTER III.

THE CHANGE OF SEASONS.—THE VARIATION IN THE LENGTH OF DAY AND NIGHT.

129. Suppose the Earth's Axis were perpendicular to the Plane of the Ecliptic—then the plane of the ecliptic would coincide with the equator, and the sun would, accordingly, always be seen over the equator. His northernmost rays would always strike exactly at the north pole; his southernmost rays, at the south pole; those rays which reach us would come in precisely the same direction every day throughout the year; and there would be nothing to produce a change of seasons except the difference in our distance from the sun at different points of the orbit (§ 47). This difference, however, is so extremely slight that in all probability ordinary observers could not detect any difference,* and, consequently, there would be perpetual winter in the frigid zones, perpetual spring in the temperate zones, and perpetual summer at the equator.

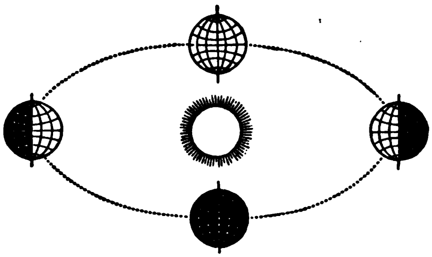

Fig. 27. *Axis perpendicular to Ecliptic.*

126. *Show how Fig. 26 corresponds with Fig. 23.* 127. Whence do the tropics derive their names? Why? 128. What are the effects of the sun's declinations?

Chap. III.—129. *What would be the result, if the earth's axis were perpendicular to the plane of the ecliptic? What would be the only condition to produce a change of seasons? Would this condition be sufficient to produce such an effect?*

* Whatever difference there might be, would be just opposite to that produced by the sun's declinations, at least in the northern hemisphere, for we are nearest the sun in winter.

Every parallel circle would be half the time in the sunlight and half the time in the shade (See Fig. 27), so that day and night would be equal throughout the year at every point on the earth's surface—a perpetual equinox—except at the poles, where the sun would always be seen in the horizon.

130. The Change of Seasons.—We have seen (Chap. II.—Sec. III.) that the change of seasons is due to differences in the direction of the sun's rays, which beat almost directly upon our heads in midsummer, and fall very obliquely in midwinter. Also (§ 124), that these differences of direction, in other words the sun's declinations, are produced by the inclination and unchanging direction of the earth's axis, together with the earth's yearly revolution around the sun. (*Man.* 37.)

Fig. 28. *The Change of Seasons.*

131. The Variation in the Length of Day and Night.—This change is due to the same cause that produces the change of seasons; for, when the sun is north or south of the equator, more or less than half of each parallel, except the equator, is in the sunlight at a time, as may be seen from Figs. 30

How would the day compare in length with the night, throughout the year? 130. To what is the change of seasons due? How are differences in the direction of the sun's rays produced? 131. Explain the variation in the length of day and night?

and 32, or from the right and left of Fig. 28. At these times, therefore, we are more or less than 12 hours in passing through the sunlight or shade. (*Man.* 38.)

(The same truth was shown in a different manner from Fig. 17, § 95.)

Both summer heat and winter cold are thus increased; for the sun shines upon us in summer, not only more directly, but for more hours at a time, than in winter.

Let us now examine, in regular order, the changing relations which the earth bears to the sun at different points of its orbit.

132. The Vernal Equinox, *20th of March.*—The sun enters the sign Aries. (See bottom of Fig. 28. The sun, as seen from the earth in this part of its orbit, appears in Aries.) Neither pole of the earth inclines toward or from the sun, but *sidewise;* consequently, the sun is vertical at the equator, his northernmost and southernmost rays fall at the poles, and day and night are everywhere equal. It is spring in the northern, and autumn in the southern, hemisphere.

Fig. 29. *Earth at Vernal Equinox.*

As the earth moves on from the vernal equinox, the north pole begins to lean toward the sun and the south pole from it; the sun, therefore, is vertical farther and farther north of the equator each day (See Fig. 26), until—

133. The Summer Solstice, *21st of June.*—The sun now enters Cancer. The north pole leans exactly toward the sun, and the south pole exactly from it; consequently, the sun is vertical $23\frac{1}{2}°$ north of the equator, and, if his

What effect has this on the extremes of heat and cold? 132. What is the date of the vernal equinox? What sign of the zodiac does the sun enter at this time? How do the poles of the earth incline with reference to the sun? Where, then, is the sun vertical? Where do his northernmost and southernmost rays fall? What of day and night? What season in each hemisphere? What changes take place as the earth moves from the vernal equinox? 133. What is the date of the summer solstice? What sign does the sun enter at this time? How do the poles incline?

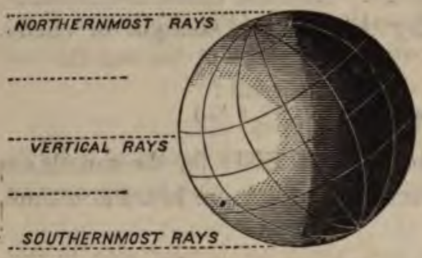

Fig. 30. *Earth at Summer Solstice.*

vertical rays should leave a track as the earth turns upon its axis, they would mark the tropic of Cancer upon the surface (Fig. 30).

The northernmost ray of the sun falls 23½° beyond the north pole, and would, if it left a track, mark the arctic circle as the earth turns upon its axis. The southernmost ray falls 23½° short of the south pole, and describes the antarctic circle. (*Man.* 32 *and* 33.)

No point within the arctic circle passes out of the sunlight, and no point within the antarctic circle passes into the sunlight, during the earth's rotation; hence a 24 hours' day within the former, and a 24 hours' night within the latter. The long *twilight*, however, practically shortens the night very much in the antarctic circle—excepting in a small space around the pole. (See p. 39, note at bottom.) (*Man.* 40.)

More than half of each parallel circle in the northern hemisphere is in the sunlight at a time, and less than half of each parallel circle in the southern hemisphere; consequently, the days are longer than the nights in the former, and shorter than the nights in the latter. It is summer in the northern, and winter in the southern, hemisphere.

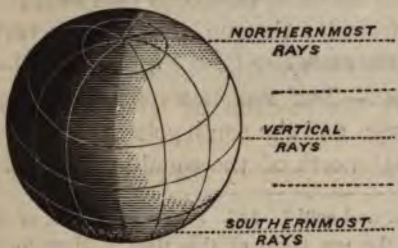

Fig. 31. *Earth at Autumnal Equinox.*

From the summer solstice, the poles incline less and less toward and from the sun, and the sun's vertical rays fall farther and farther south, until—

134. The Autumnal Equinox, *23d of September.—Questions:—*

1. What sign does the sun enter? (See Fig. 22, p. 55, for sign opposite ♈.)

2. What season is it in the northern hemisphere? In the southern?

What circle does the sun's vertical ray describe? His northernmost ray? His southernmost ray? Where is there continuous day? Continuous night? How does day compare with night in the northern hemisphere? In the southern? From the summer solstice, what changes takes plaee? 134. Questions.

3. How do the poles lean with reference to the sun? (Fig. 31.)

4. Where do the northernmost and southernmost rays of the sun fall?—Then, on what circle of the earth do the vertical rays fall?

5. What is the length of day and night?

6. If we could see the equinoctial and ecliptic as great circles of light in the sky (Fig. 22, p 55), where, with reference to them, should we see the sun?

Ans. The sun is *always* in the ecliptic, and, since he is now also in the equinoctial, he must be where the two circles cross each other—the autumnal equinox.

135. The Winter Solstice, 21*st of December.—Questions:—*

1. What season in each hemisphere?

2. At what circle of the earth is the sun vertical?

3. Which pole leans exactly toward the sun?

4. Where do the northernmost and southernmost rays fall?

5. In which zone is there a twenty-four hours' day? In which a twenty-four hours' night?

6. How does the day compare with the night in each hemisphere?

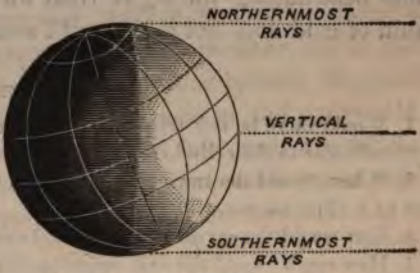

FIG. 32. *Earth at Winter Solstice.*

ADDITIONAL OBSERVATIONS.

136. Day and Night at the Poles are each six months in length. From March 20th to September 23d, the north pole remains constantly in the sunlight, and the south pole, in the shade. From September 23d to March 20th, the conditions are reversed. (*Man.* 41.)

We arrive at the same result by reflecting that the poles are not affected by the earth's daily motion; we have already learned that, if it were not for this motion, the day and night would be six months each throughout the year.

Within the frigid zones, day and night each vary all the way from 6 months at the poles, to 24 hours at the polar circles (§ 133, par. 3).

135. Questions. 136. Describe day and night at the poles. *How else may we arrive at this result? Describe day and night between the poles and polar circles.*

137. Seasons at the Equator.—The sun crosses the equator and departs to its greatest distance from the equator twice during the year. There are, consequently, two summers and two winters annually at the equator, although "winter" there must, of course, be much warmer than our warmest summer.*

138. The full Effects of the various Changes in the Direction of the Sun's Rays are not felt at once.—Although the most direct rays fall at noon, the warmest part of the day is usually two or three hours later. So, although the hottest rays fall at the summer solstice, yet our warmest weather does not come until some time afterward. We continue to receive more heat during the days following than we lose during the nights. Thus, the great heat of a July or August day is not produced entirely by the sun of that day, but is an accumulation of the heat of the several preceding weeks. For a like reason, we do not experience the greatest cold at the winter solstice. We continue to lose more heat during the night than we receive during the day, and the maximum of cold does not arrive until some time in January.

Exercises.

1. Would there be any tropics or polar circles, if the earth's axis were not inclined from a perpendicular to the ecliptic?
2. Where would the tropics be, if the axis were inclined 45°? Where would the polar circles be? (Fig. 25, p. 61.)
3. How would the extremes of heat and cold compare with those we experience?
4. How much should the axis be inclined to bring the tropic of Cancer to New York?
5. How much should the axis be inclined to bring the arctic circle to New York?
6. If the axis were thus inclined, how long would be the day and the night at the summer solstice, at New York? Where would the sun be seen at the winter solstice?

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137. Describe the seasons at the equator. 138. Why are not the full effects of the various changes in the direction of the sun's rays, felt at once?

* The only seasons practically known in tropical climates, are the "wet" and the "dry."

SECTION SIXTH.—THE EARTH AND MOON.

CHAPTER I.

THE MOTIONS OF THE MOON.

139. The Moon's Sidereal Revolution around the Earth.—The moon revolves around the earth, from any point in the zodiac round to the same point again, once in $27\frac{1}{3}$ days. This is called its *sidereal* [1] revolution.

140. *How we know that the Moon revolves around the Earth.*—We have learned (§ 109) that the stars are fixed, and only *seem* to move as the earth turns on its axis. If we observe among what stars the moon appears to-night, to-morrow night we shall see it considerably east of these stars; the next night it will appear still farther east; and, in $27\frac{1}{3}$ days, we shall see that it has completed the circuit. Now, we know that the earth performs no motion which could cause the moon to seem to move in this manner, therefore the moon must actually perform the motion.

141. Since the moon moves entirely round the zodiac in $27\frac{1}{3}$ days, it must require a little more than two days ($27\frac{1}{3} \div 12$) for it to move from one sign to another.

142. *Ex.* 1. If the moon moves through the whole circle in $27\frac{1}{3}$ days, how many degrees does it move in 1 day? In what direction?

2. Then, if it rises at the same instant with a certain star to-day, will it be above, or below, the eastern horizon when that star rises to-morrow, and *how much*—supposing its orbit to be perpendicular to the horizon? *Ans.* About $13\frac{1}{6}°$ ($360° \div 27\frac{1}{3}$) below.

3. How much *later* than the star will it rise to-morrow? (1 hour of time corresponds to 15° of daily motion.) *Ans.* About 52 minutes.

CHAP. I.—139. What is the moon's sidereal revolution? In what time is it performed? 140. How may we observe the moon's revolution around the earth? 141. How long is the moon in moving through one sign of the zodiac? 142. *Examples.*

(1) Sidereal; *sidera,* stars.

143. The Moon's Synodic Revolution.—If the sun appeared stationary in the zodiac, like the stars, the moon would require 27⅓ days to move from the sun's place in the sky round to the same place again. But we have seen that the sun's place is also moving eastward at the rate of one sign, or 30°, a month; so that, when the moon comes round to the place in which she left him 27⅓ days before, she finds that he has gone forward nearly one entire sign. She will, therefore, require a little more than 2 days to overtake him (§ 141), making her whole time, from sun to sun, about 29½ days —her *synodic* revolution. (*Man.* 44.)

144. *The Moon rises, on an average, nearly an Hour later each Day.—Questions:—*

1. Since the moon moves 13⅓° per day in the zodiac (§ 142), while the sun seems to move about 1° per day (§ 110, Ex. 6), how much does the moon gain on the sun each day, and how much time does this difference represent—supposing the moon's orbit to be perpendicular to the horizon? (§ 142, Ex. 3.)

2. Then, if the sun and moon rise at the same instant to-day, which will rise the earlier to-morrow, and what will be the difference in time—supposing &c.? *Ans.* 48⅘ minutes.

The *average* length of the lunar day, or time between moon-rise and moon-rise, is 24 hours and about 48 minutes. (*Man.* 47.)

THE PHASES OF THE MOON.

145. Their Cause.—One-half of the moon's surface, like that of the earth, is always lighted by the sun; and, in consequence of the moon's monthly revolution around the earth, we see more or less of that lighted half at different times during the month. The different appearances thus presented are called the moon's *changes*, or *phases*.[1]

New Moon.—When the moon has passed round to the sun's place in the zodiac, that is, when it stands between us and the sun, its lighted half is turned entirely from us. It is now said to be *new*.

Crescent.[2]—As it slowly moves eastward, it soon emerges from the sun's rays, and we see it faintly in the sky above the setting sun. The lighted

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143. Why does it take longer for the moon (or any other planet) to move "from sun to sun," than "from star to star"? What is the former motion called? The latter? (§ 139.) In what time is the moon's synodic revolution performed? 144. *Questions.* 145. Define and explain the moon's phases.—New moon.—Crescent.—

(1) Phases; *phasis*, an appearance.
(2) Crescent; *crescens*, growing.

alf is now turned a very little toward us, so that we can discern a delicate dge of it; which widens night after night, as the moon moves farther east-vard from the sun.

First Quarter.—When it has erformed the first quarter of ts revolution, and is on the neridian at sunset, one-half of ts lighted half is turned toward is. We thus see one-half of its lisk lighted, which we, accord-ngly, call a "*half-moon*," al-hough it is only one-fourth of he whole surface.

Gibbous.[1]—Moving still far-her eastward, we see more han half its disk lighted, which gives it an uneven, oval ap-earance.

Full.—When it has perform-d half its synodic revolution, and is, therefore, *opposite* the sun, its whole lighted half is turned toward us. Its whole disk is now bright, and we call it the *full moon.*

FIG. 33. *Phases of the Moon.*

Ex. In what part of the sky must we look for the full moon at sunset? At midnight? At sunrise? (See Fig. 33, with explanation at the top of page 74.)

Waning.—From full, the moon begins to approach the sun again, and its lighted half is turned more and more from us. It becomes gibbous—passes through its last quarter—takes again the crescent form—is finally lost in the sun's rays—and its synodic revolution is completed. (*Man.* 46.)

Ex. 1. In what part of the sky do we see the moon in the last quarter, at sunrise?

2. About how many days are there from new moon to first quarter? From new to full moon?

In Fig. 33, the central sphere represents the earth; the ring of disks around it, the moon in eight points of her orbit with that half next the sun always lighted; and the outer disks

First quarter.—Gibbous.—Full.—*Examples.*—Waning. *Examples.* *Explain Fig.* 33.

(1) Gibbous; *gibbosus*, humped.

show the moon as she appears to us in the eight positions. An observer upon the earth at *a* sees the sun setting in the west (toward the right of the engraving). Then, if the moon were *new*, it would set at the same time with the sun; if *crescent*, it would appear above his western horizon; if in *first quarter*, on his meridian; if *gibbous*, above his eastern horizon; if *full*, in his eastern horizon. An observer at *b* sees the sun rising in the east. Then, if the "old" moon were *crescent*,* it would appear above his eastern horizon; if in *last quarter*, on his meridian; if *gibbous*, above his western horizon; and if *full*, in his western horizon.

146. The Moon's Orbit is an ellipse (§ 100), with the earth at one focus. The point nearest the earth is called *perigee*, and the point most distant, *apogee*. The difference between the distances of these points is about 26,000 miles. (*Man.* 42.)

147. *Inclination of the Moon's Orbit.*—The moon's orbit is inclined about 5° to the ecliptic (Fig. 24, p. 60). The points in which she crosses the ecliptic are called her *nodes*[1]: that from which she passes north, is called her *ascending* node (☊); and that from which she passes south, her *descending* node (☋). (*Man.* 43.)

Ex. 1. When the moon is farthest from the ecliptic, how many degrees is she still within the edge of the zodiac? (§ 112.)

2. At which node is the moon represented in Fig. 24?

148. The Moon's Rotation.—Let a person walk around you: if he continues facing toward the same point of the compass, that is, if he does not *rotate*, you will see his face, sides, and back in succession. If, however, he faces you all the time, he will turn completely round on his heels just once, while he moves once around you. The fact, that the moon always presents the same side to us, shows that it turns once upon its axis while it revolves once around the earth. (*Man.* 48.)

[Fig. 34 presents a telescopic view of the "half-moon." Upon its surface, we see what must be multitudes of lofty, rocky mountains; wide, desolate plains; black, yawning caverns; and, in short, the general evidences of violent volcanic action (§ 17). The most peculiar feature, however, of the moon's surface, is the great number of huge *craters*, or

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146. Describe the moon's orbit. Perigee and apogee. 147. How is the moon's orbit inclined to the ecliptic? What are the moon's nodes? *Examples.* 148. Illustrate the moon's rotation.

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* Or rather, *de-crescent (decreasing)*.

(1) Node; *nodus*, a knot.

is, which are seen in all parts of its disk. These consist of rough walls of circular often surrounding a cone-shaped hill in the middle, the bottom of the craters being ly much lower than the surface outside.

arvest and Hunter's ı.—In § 142 and § he moon is proved to nearly an hour later, after day, *upon the tion that her orbit is endicular to the hori-* But, since her orbit t slightly inclined to cliptic (§ 147), and the ecliptic is always or less inclined from tical, in our latitude, ength of the lunar varies at different . In September, for ple, the moon, at and her full, rises at near- same time (sunset) veral successive days, use, although she s her $13\frac{1}{6}°$ daily in r orbit, yet the latter slightly inclined to orizon that the mo- hanges but slightly lations to the horizon as a man, walking line nearly parallel a fence, makes but a paratively slight e in his distance he fence. The bright ight thus seems to ut the busy harvest whence its name. g the next month, er,—the month for g,—the path of the full moon is again much inclined from a vertical, and hence a similar, though less marked, phenomenon , *which is called the "Hunter's Moon."*]

FIG. 34. *Telescopic View of the Moon in Quadrature.*

CHAPTER II.

A FEW OF THE SIMPLER FACTS CONCERNING ECLIPSES.

149. Cause of Eclipses.—Like every other opaque body, both the earth and moon cast shadows; and, when the shadow of either falls upon the other, the phenomenon is called an *eclipse.*

FIG. 35. *Eclipses.*

150. Solar Eclipses.—When the shadow of the moon falls upon the earth (Fig. 35), the whole or a part of the sun's disk is hidden from observers within the shadow, and a *solar* eclipse is produced. If the sun is entirely hidden, the eclipse is called *total*, if only in part, *partial*. (*Man.* 51.)

151. Lunar Eclipses.—When the moon passes through the earth's shadow, as represented in the lower part of Fig. 35, its surface is darkened, and a *lunar* eclipse is produced. (*Man.* 52.)

The engraving exhibits some of the more important features of eclipses. It shows us:

1. *The Form of the Shadows.*—Both earth and moon being smaller than the sun, their shadows are *conical.*

2. *Two Kinds of Shadow.*—A perfect shadow, or *umbra*, is shown by the dark shading; and a partial shadow, or *penumbra*, is shown by the light shading. An observer within the *umbra* would see a total eclipse, while one within the *penumbra* would see only a partial eclipse.

3. *Extent.*—The extent of surface, within which an eclipse of the sun is visible at a time, is comparatively small; while an eclipse of the moon is visible from nearly half the earth's surface at a time. As the earth turns on its axis, however, both shadows are carried over a much greater extent of surface than the figure represents.

CHAP. II.—149. What are eclipses, and how are they caused? 150. Explain solar eclipses—total and partial. 151. Lunar eclipses. What does Fig. 35 exhibit? Describe from it, —*the form of* the shadows; two kinds of shadow; the extent of the shado ws.

152. When Eclipses may occur.—*Questions on Fig.* 24 (*p.* 60):—

1. At which node is the moon represented?
2. Would an eclipse take place if the moon were in this position? Solar, or lunar?
3. Would an eclipse take place if the moon were in the opposite position? Solar, or lunar?
4. Can an eclipse occur excepting when the moon is at one of her nodes? *Ans.* A partial eclipse may occur when she approaches *very near* a node.

Our first result, then, is that *the moon must be at or near a node* in order that an eclipse may occur. Still another condition is necessary.

5. What *phase* (§ 145) of the moon occurs when she is between the earth and sun, as represented in the figure? When she is in the opposite position?
6. Suppose the moon should cut the plane of the ecliptic at a point very much *this side* of that at which she is represented; would she not be at a node? (§ 147.)
7. Would she be either new or full at the same time?
8. Would an eclipse occur?

Thus, it is evident that, in order that an eclipse may occur, *the moon must be at or near a node at the same time that she is new or full. (Man. 50.)*

Now, the moon's nodes revolve in the plane of the ecliptic once in about 18 years and 10 days. Therefore, the next time the moon comes to the node at which she is represented in the figure, it will be a little *one side* of the line connecting the earth and sun; the next time, it will be still farther one side, etc.

Hence, eclipses *alike in all respects* occur at intervals of about 18 years and 10 days. Eclipses of *different kinds*, generally partial, take place from two to five times a year.

153. Annular Eclipses.—Sometimes a solar eclipse occurs when the sun is nearest, and the moon most distant from, the earth. At this time, the disk of the moon appears smaller than that of the sun: for this reason, when the centers of the two disks coincide, a bright ring of the sun will be seen encircling the black disk of the moon. This is called an *annular*[1] eclipse.

Exercises.

1. When an eclipse occurs at new moon, is it a solar, or a lunar, eclipse?
2. When an eclipse occurs at full moon, is it a solar, or a lunar, eclipse?
3. When a total solar eclipse is visible from the earth, what is the appearance of the earth as seen from the moon? (Fig. 35.)
4. When a total lunar eclipse is visible from the earth, what occurs upon the moon? (Fig. 35.)

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152. *Questions.—What conditions are necessary to produce an eclipse? Are the moon's nodes stationary? How often do eclipses alike in all respects occur? Of different kinds?* 153. What are annular eclipses, and how are they caused?

(1) Annular; *annulus*, a ring.

CHAPTER III.

THE TIDES.

154. The Tides are the alternate rising and falling of the water of the ocean and its arms twice a day. They are caused by the difference in the attraction of the sun and moon for the earth and the ocean, as the latter passes under these bodies during the daily motion of the earth. The rising is called the *flow*, and the falling, the *ebb*. (*Man.* 56.)

155. Different Heights of the Solar and Lunar Tides.—On account of its immensely greater distance, the tides influenced by the sun are only about one-third as high as those influenced by the moon. When we speak of "the tides," therefore, we generally refer to the lunar, rather than the solar, tides.

156. The Tidal Waves not directly under the Sun and Moon.—It requires a considerable time to elevate the vast body of water which forms a tidal wave; so the *full effect* is not produced at any place, until some hours after

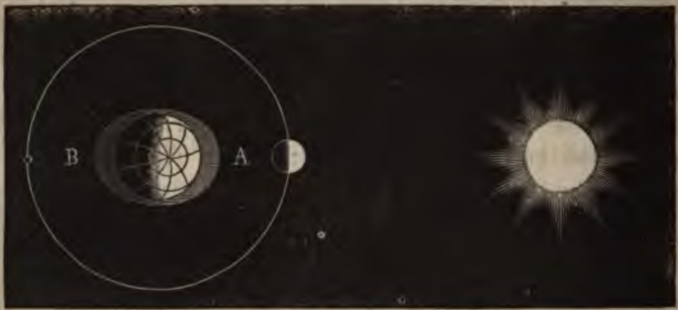

Fig. 36. Spring-Tides—New Moon.

the sun or moon has passed over it.

For convenience, however, we will suppose the tidal waves to be in the same line with the sun and moon, as represented in the figures.

CHAP. III.—154. What are the tides, and how are they caused? Define *ebb* and *flow*. 155. How do the sun-tides differ from the moon-tides? To which does the general expression "the tides" refer? 156. Are the tidal waves directly under the sun and moon? Why not? What allowance must be made in the remainder of this chapter?

7. Tides on opposite Sides of the Earth.—Not only does the water under the sun and moon, but also on the opposite side of the earth at the time. This may be explained as follows:

e nearer particles of matter are to one another, the more powerful is mutual attraction (§ 24). For this reason, the water at A, Fig. 36, nearer the sun and moon than the rest of the earth, is heaped up by influence, while that at B, not being *so closely hugged to the surface* as here, is left heaped up in a similar manner.

3. Spring-Tides.—When the sun and moon are in the same line with the , as at new moon, Fig. 36, and full moon, Fig. 37, the solar and lunar

FIG. 37. *Spring-Tides—Full Moon.*

come together and form a single wave on either side of the earth, A and This union of the solar and lunar tides is called the *spring-tides*. (*Man.*

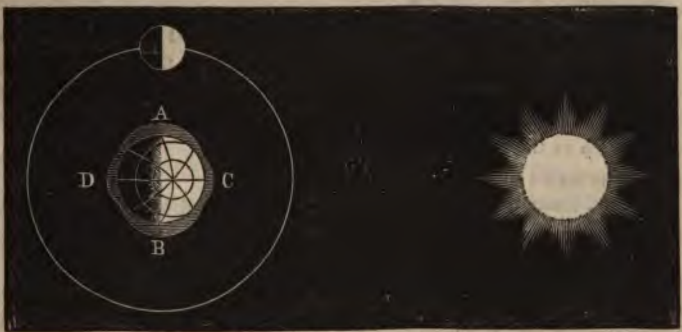

FIG. 38. *Neap-Tides—Moon in Quadrature.*

. Why do tides occur on opposite sides of the earth at the same time? 158. Explain -tides.

Ex. 1. How does "high-water" at spring-tide, compare with the same at any other time, when the solar and lunar tides are more or less separated?

2. How many times does spring-tide occur during the month?

159. Neap-Tides.—As the moon moves eastward from the sun, her tide follows her leaving the solar tides behind, until at quadrature, Fig. 38, the two tides are farthest apart. This is called *neap-tide.*

Ex. 1. How does "high-water" at neap-tide compare with the same at any other time, when the solar and lunar tides *commingle* to some extent?

2. How many times does neap-tide occur during the month? (*Man.* 55.)

160. Varying Height of the Tides in different Places.—The height of the tides is very different at different parts of the earth's surface. It is greatest in the equatorial regions, over which the sun and moon perform their apparent circuits; and least in the polar regions. It is hardly perceptible in the open sea, rising only from one, to two and a half feet. But, as the vast wave rolls up on the shore, it *redoubles on itself*, and sometimes rises to wonderful heights, especially when it is forced into a narrow bay or inlet. In the Bay of Fundy, for example, it rises from 60 to 70 feet. (*Man.* 53.)

EXERCISES.

1. How often would the lunar tides rise, if the earth did not turn upon its axis? How often would the solar tides rise?

2. Are the sun and moon *exactly* in the same line from the earth at any other time than during an eclipse?

3. How, then, does the height of the tides during an eclipse compare with their height at other times, other things being equal?

4. The descent of some rivers, near their mouths, is so slight that their waters flow very slowly into the ocean at low-tide. In what direction must the flow be at high-tide?

5. Why do we not perceive tides in ponds and lakes when the moon passes over them?

6. The atmosphere surrounds the earth like an aërial ocean; what effects must follow upon its outer surface as the sun and moon circle around it?

7. Are there perceptible tides in the polar regions?

8. If the solar and lunar tides are together to-day, how long will it be before they will be together again?

Examples. 159. Neap-tides. *Examples.* 160. How do the tides vary in height in different places?

SECTION SEVENTH.—TIME.

CHAPTER I.

DIVISION OF TIME.—THE DAY.

161. The Heavens a Time-piece.—The sky is the dial of a perfect time-iece, and our clocks and watches only imitate on a small scale some of the ıovements which really or apparently take place there.

162. *The Hour-hand of the Heavens* is the sun, which seems to move com-letely around the great dial, marking the 24 hours of the solar day. Each :ar also serves as an hour hand, measuring the 24 hours of the sidereal ay, which, we remember, is about 4 minutes shorter than the solar day.*

163. *The Month-hand* is also the sun, which seems to move from sign to gn in the zodiac, precisely as the hour-hand of a clock moves from hour › hour.†

164. Time of Day at the same Instant, at different Points.— *Questions :* —

1. Over how much of a parallel is it noon at the same instant? Sunrise? unset? Midnight?

2. Over how much of a meridian is it noon at the same instant? Sunrise? unset? Midnight?

CHAP. I.—161. What is the great standard for the measurement of time? 162. How ›es it measure the hours and days? 163 The months and years? 164. Questions.

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* The sidereal day, with its hours, minutes, and seconds, is measured by the astronomical ock. It always begins when the vernal equinox comes to the meridian, and is reckoned ›m 0 hours to 24 hours.

† *Other Divisions of Time* are measured by—the moon's synodic revolution around the rth, *a lunar month,*—the revolution of the moon's nodes around the ecliptic, which consti-tes the *Saros,* or period between eclipses,—the westward revolution of the equinoxes around e ecliptic once in about 26,000 years, the *equinoctial cycle* (Supplement § III),—the revolu-›n of the aphelion and perihelion points around the earth's orbit once in about 115,000 :ars, etc.

3. When it is 12 o'clock, noon, at 0° longitude, what time is it at 180° longitude?

4. Over how many degrees of longitude does the sun seem to pass in 12 hours? In 1 hour? In 4 minutes?

5. When it is sunrise with us, is it before, or after, sunrise at points east of us? At points west of us?

6. When it is sunrise with us, what time is it 1° east of us? 1° west of us? *Ans. to last*, 4 minutes before sunrise.

7. When it is noon at New York, what time is it at London, 74° east of New York? What, then, is the difference between "London time" and "New York time"?

8. Suppose a traveler sets his watch in London, and does not set it again until he arrives in New York; will he find it too fast, or too slow, and how much?

9. What is the difference between Boston and Chicago time?

[SEE SUPPLEMENT I.]

CHAPTER II.

THE YEAR.—THE CALENDAR.

165. The Natural, or Tropical, Year is the actual time required for the earth to perform its revolution around the sun, from opposite a certain point in the zodiac round to the same point again, viz., a little less than 365¼ days (365d. 5h. 48m. 50 sec.). (*Man.* 58.)

166. The Common Year is the even number of days required for the earth's revolution, viz., 365.

167. Leap-year.—Since each common year is nearly ¼ of a day too short, four common years would be nearly a day too short. Accordingly, a day is added every fourth year to make up the deficiency, by making February consist of 29 instead of 28 days. The year thus increased, is called *leap-year*.

CHAP. II.—165. What is the natural, or tropical, year? 166. The common year? *167. Leap-year?*

168. *Origin of Leap-year.*—Before the time of Julius Cæsar, the Romans used only the ommon year of 365 days. Thus, their calendar gained nearly $\frac{1}{4}$ of a day annually on the atural year. This went on for more than 360 years, when, of course, their calendar had ained (360 × $\frac{1}{4}$) about 90 days.

The inconvenience which resulted, was very similar to that we experience from a watch which has been slowly, but steadily, gaining on the natural day for a long time. As the "12 o'clock" of such a watch may arrive in the morning or evening, rather than, as it should, at noon or midnight, so the winter months of the Romans finally arrived in the natural fall, and the summer months, in the natural spring.

For the same reason, therefore, that we turn the hands of a watch that has been gaining, back to the proper points, the Romans *carried back* their date 90 days, bringing the winter months to the *actual* winter, and the summer months to the actual summer. Thus, they added 90 days to that year (45 B. C.), making it 455 days long! Well might it be called the "Year of Confusion!"

To prevent a repetition of the error, Cæsar established the leap-year,* which, as we have seen, *sets back* the calendar one day every four years.

169. *Number of Leap-years in a Century.*—The natural year is *not quite* $\frac{1}{4}$ of a day over 365 days. In adding an entire day every four years we add about $\frac{3}{4}$ of an hour *too much*; which, in 100 years, amounts to about $\frac{3}{4}$ of a day. To correct this error, we omit the additional day from the 100th year, leaving only 24 leap-years in a century.

170. *Number of Leap-years in four Centuries.*—But the error in 100 years really amounts to only $\frac{3}{4}$ of a day (§ 169), whereas we omit an entire day, or $\frac{1}{4}$ of a day too much; which, in 400 years, amounts to 1 day too much. To correct this error, we do *not* omit the additional day of leap-year from the 400th year. Thus, in 4 centuries there are 97 leap-years.

171. **Summary of Corrections for the Calendar.**—Like an imperfect watch, our calendar must be regulated by being—*first*, set back 1 day every fourth year; *secondly*, set forward 1 day every century; *thirdly*, set back 1 day every fourth century.

172. *The Gregorian Rule.*—Pope Gregory XIII, who established the last two corrections, embodied all three in the following rule:

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168. *Which of these did the ancient Romans use? What was the consequence? Illustrate the inconvenience which resulted. How, and why, did the Romans correct their calendar? How was a repetition of the error prevented?* 169. How many leap-years in a century? 170. In 4 centuries? 171. Repeat the corrections for the calendar. 172. The Gregorian rule.

* Called *Bissextile* by the Romans.

Every year whose number is not divisible by 4 *without a remainder, consists of* 365 *days; every year whose number is divisible by* 4, *but not by* 100, *of* 366 *days; every year whose number is divisible by* 100, *but not by* 400, *of* 365 *days; and every year whose number is divisible by* 400, *of* 366 *days.*

Exercises.

1. How many days in the year 1870? 1872? 1900? 2000? (§ 172.)
2. If the common year should remain uncorrected for 100 years, how much would the calendar gain on the natural year?
3. If the Julian year ($365\frac{1}{4}$ days) should remain uncorrected for 1,600 years, how much would the calendar fall behind the natural year?

CHAPTER III.

THE ALMANAC.

173. The Names of the Months and Days of the Week are derived chiefly from the names of ancient cities or heroes.* The last four months, however, are named from the Latin numerals, *septem*, seven; *octo*, eight; *novem*, nine; *decem*, ten. At the founding of Rome the year began with March, consequently September was the *seventh* month, instead of the *ninth* as now.

174. The Dominical[1] Letter.—This means the letter for the *Lord's Day*. We often see Sunday distinguished from the other days in almanacs, by a certain capital letter, which changes every year and, on leap-years, twice. The first seven letters of the alphabet are used for this purpose.

175. *Its Use.*—There is not an exact number of weeks in a common year. 365 divided by 7 gives a remainder of 1. If a year begins on Sunday, therefore, the next year will begin on Monday, the next on Tuesday, etc.

Chap. III.—173. *How are the names of the months and days of the week derived?* 174. *What is the Dominical Letter?* 175. *Explain its use.*

* *The Days of the Week* are thus derived: Sunday, *Sun's day;* Monday, *Moon's day;* Tuesday, *Tiig's day;* Wednesday, *Woden's day;* Thursday, *Thor's day;* Friday, *Frigga's day;* Saturday, *Saturn's day.*

(1) Dominical; *Dominus*, Lord.

The Dominical Letter A denotes that Sunday was the 1st day of January; B, that Sunday was the 2d day of January, and so on.

As there are 366 days in a leap-year, or two days over an exact number of weeks, *two* Dominical Letters are used—the first until the 29th of February, and the second during the remainder of the year.

By the aid of the Dominical Letter and tables sometimes published in almanacs, we can tell upon what day of the week any day of any year has fallen or will fall.

176. The Moon's Age is the time that has passed since the moon was new. Thus, the age of the moon at full is about 15 days.

177. *The Epact* for any year is the moon's age on January 1st of that year. Thus, if the moon is new when the year comes in, the epact is 0; if the moon is full when the year comes in, the epact is about 15 days. (*Man.* 59.)

178. The Lunar, or Metonic, Cycle.—Every 19 years the epact is the same; if, for example, the moon is 10 days old at the beginning of this year, in 19 years she will again be 10 days old at the beginning of the year. This period of 19 years is called the *lunar*, or *Metonic, cycle*[1]. It measures the intervals at which the same phases of the moon occur on the same days of the month. Thus, if the moon is full on Christmas this year, it will not be full again on Christmas for 19 years.

179. *The Golden Number** of any year is the number of that year in the lunar cycle Thus, the golden number of the year which begins the cycle is 1; of the year which finishes it, 19. The golden number of 1872 is 11.

By knowing the golden number of a year, we can readily find the epact, from which we may fix the moon's age for any day of the year.

Why are two Dominical Letters necessary for leap-years? What may be determined from the Dominical Letter? 176. *What is the moon's age?* 177. *The epact?* 178. *The lunar cycle?* 179. *The golden number?*

(1) Metonic cycle; so called from Meton, its discoverer.

* Golden number; so called because it was inscribed in the calendar in letters of gold.

EXERCISES FOR REVIEW.

1. Of what is the earth a part?—2. How large a part?—3. Prove that it is spherical (§ 6, etc.). —4. What made it so? (§ 4.)—5. Prove that it is spheroidal (§ 22, etc.).—6. What made it so? (§ 18.)—7. What is its diameter?—8. Its circumference?—9. How many square miles in its surface? (§ 25.)—10. How does it compare in size with the sun?—11. With the moon? (§ 51, etc.)—12. How much is it flattened at its poles? (§ 21.)—13. How much heavier is it than an equal bulk of water? (§ 54.)—14. What fixes the position of its equator and poles? (§ 26.)—15. How many different points upon its surface are in the same latitude?—16. In the same longitude?—17. In the same latitude *and* longitude?—18. What is the prime meridian?—19. What may be called the *prime parallel?*—20. Which is the longer—a degree of the parallel passing through London, or of that passing through Washington? (§ 34.)—21. What zones are not *belts?*—22. Give the breadth of each zone in degrees? —23. What circles separate the zones, and what fixes the position of these circles?—24. How would the sky appear by day if it were not for the air? (§ 68.)—25. Why is it not dark the moment the sun has set?—26. Why is it not as light and warm at sun-rise as at noon? (§ 77, etc.)

27. Describe the earth's motions.—28. Why do they not cease?—29. Effects of its rotation? (§ 84.)—30. Prove that it rotates (§ 89).—31. Which *seems* to rotate, the earth or the starry sphere?—32. Would this be the appearance to a spectator in space?—33. How does the north star indicate north latitude? (§ 96.)—34. What prevents the earth from flying off into space? (§ 98.)—35. From falling to the sun?—36. What is the form of its orbit?—37. Define *perihelion* and *aphelion*, (§ 101.)—38. What are the directions of the earth's motions? (§ 104.)—39. What are the effects of its yearly motion? (§ 107.)—40. If the sun were visible at the same time with the stars, would it always appear in the same place among them? (§ 108, etc.)—41. How much would it appear to move in one day? (§ 110.)—42. In what direction?—43. Along what line?—44. Through what belt of the starry heavens? (§ 112, etc.)—45. What is the cause of this apparent motion?—46. Why is a picture of a ram placed upon the Almanac page for March?

47. What is the name of the plane cutting through the center of the earth and the ecliptic? (§ 117.) —48. Is the earth's axis perpendicular to this plane?—49. What would be the results if it were so? (§ 129.)—50. What is its true attitude in the plane?—51. When does the north pole lean exactly toward the sun? (§ 133.)—52. Upon which circle of the earth do his vertical rays then fall?—53. Is the sun then high or low in the heavens, at noon?—54. How does day compare with night, in length,—55. What then, is the season at this time?—56. When does the north pole lean exactly from the sun?—(*Repeat Questions* 52, 53, 54, 55.)—57. When do the poles lean neither toward nor from the sun?—(*Repeat Questions* 52, 53, 54, 55.)—58. What is the length of day and night at the poles?—59. Of the longest day and night at the polar circles?—60. At the equator? (§ 95.)

61. Is the moon always seen among the same stars? Why not? (§ 139.)—62. How long before it will again occupy its present position?—63. What is the name of this motion?—64. If the moon is beside the sun to-day, where will it appear to-morrow?—65. In what time will it be again beside the sun?—66. What is the name of this motion?—67. Describe and explain the *moon's phases* (§145). —68. How often does the moon rotate? (§ 148.)—69. Define and explain *eclipses* (§ 149, etc.).—70. What two conditions are necessary to eclipses? (§ 152.)—71. How often do they occur?—72. Describe and explain the *tides* (§ 154).—73. Define and explain *ebb, flow, spring-tide, neap-tide.*

74. What is the standard for the measurement of time? (§ 161.)—75. What is the tropical year? Its length?—76. The common year?—77. What is leap-year?—78. Explain its necessity.—79. Repeat the *Gregorian rule* (§ 172).—80. What is meant by the moon's age? (§ 176.)—81. The epact? —82. The lunar cycle?

SUPPLEMENT.

CERTAIN MORE DIFFICULT PRINCIPLES OF MATHEMATICAL GEOGRAPHY.

I.

WHERE THE DAYS BEGIN. (See § 164.)

180. Time of Day at the same Instant, at different Points upon the Earth's Surface.—*Questions* :—

1. When it is 12 o'clock to-day at New York, what time is it 90° east of New York? 180° east? *Ans. to last,* 12 o'clock to-night.

2. What time is it at the same instant, 90° east of that point? 90° *still farther east?*

181. *A dividing Line between the Days.*—The answers to the last two questions, according to the general law, would be: 6 o'clock to-morrow morning, and 12 *o'clock to-morrow noon.* But the last departure brings us round to New York again; therefore, at New York *it is* 12 *o'clock to-day and to-morrow at once.*

This, of course, is impossible. It cannot be both to-day and to-morrow at the same instant in the same place. If we could fly around the world in a moment, we must pass some *dividing line* between to-day and to-morrow, or between yesterday and to-day; otherwise, on our return to our starting point, we should find the date changed, as shown in §180, although we had been absent but an instant.

182. *The dividing line is a Meridian passing through Alaska.*—The reason for this may be understood from the following illustration:

I. 180. *Questions.* 181. *What absurdity results from the general law relating to time at different points upon the earth's surface? If we could fly round the earth in an instant of time, what should we pass, which prevents this absurdity?* 182. *Where is the line dividing one day from another? Give the illustration.*

Suppose a number of persons, A, B, C, etc., were stationed around a circular walk, counting the number of times a pedestrian moves around it. If each regards the station *opposite his own* as the starting point (as we regard the meridian *opposite our own* as the sun's starting line—our day beginning at midnight), no two will count alike. If, however, all reckon from the point whence the pedestian *actually started in the first place*, for example, the point H, then all will count not only alike, but correctly.

FIG. 39. *Where the Days begin.*

We count the days by the apparent circuits which the sun makes around the earth; and the nations are stationed all around the earth reckoning these circuits, or, in other words, keeping the calendar. In order that all may agree upon the result, all must reckon the sun's circuits from some one starting point, as the judges, A,B,C, etc., must all reckon those of the pedestrian from H.

Now, although we know not over which meridian the sun actually started in the first place, we know where he was *at the moment when our reckoning of time begins*, viz., the midnight preceding the Saviour's birth. As we reckon from the *time* of this great event, it is eminently proper that we should also reckon from its *place*, in Western Asia. Hence, at the moment when the *first day began*, the sun must have been over the opposite meridian—one passing through Alaska. His starting point, according to our reckoning, must have been on this line. Here his first daily circuit began, and here his circuit begins to-day. This line divides one day from another *for the whole world together*, just as the midnight meridian divides one day from another *for any one place.* (*Man.* 60.) *

How do we count the days? Who upon the earth correspond to the judges, A, B, C, etc., in the illustration? What is necessary in order that all may reckon alike? Do we know where the sun actually started in the first place, as the judges know the pedestrian's starting point? What is regarded as the sun's starting point? What divides one day from another at any one point? Upon the earth as a whole?

* Mathematical reasoning thus locates the division line in long. 180° from the Saviour's birthplace. Navigators, however, find it more convenient to change their date at long. 180° from Greenwich.

II.

SUN-TIME AND CLOCK-TIME.

183. Natural and Mean Noon.—Natural noon is the time when the sun is on the meridian. Mean noon is twelve o'clock by day. The sun is on the meridian at exactly 12 o'clock on only four days during the year. On all other days, it is on the meridian from a few seconds to 16 minutes before or after 12 o'clock. When before, it is said to be "fast of the clock," and when after, "slow of the clock." (*Man.* 61.)

184. *The Equation of Time* is the difference in time between natural and mean noon. As stated above, it ranges from a few seconds to 16 minutes.

Example.—On the 1st of January, the sun is about 4 minutes "slow"; "*natural noon*" occurs 4 minutes before "*mean noon*"; and "the *equation of time*" for that day is 4 minutes.

185. *Why should there be this Difference between Sun-time and Clock-time?*—Why would it not be better to construct our clocks and watches, so that "12 o'clock" should *always* indicate the time when the sun reaches the meridian? Because the time from noon to noon, by the sun, is sometimes more and sometimes less than 24 hours, and it would be very difficult to construct a clock or watch that should follow all these variations. Our timepieces answer a better purpose by showing the *average*, or *mean*, time between noon and noon—this mean time being exactly 24 hours.

WHY THE SUN IS SOMETIMES MORE AND SOMETIMES LESS THAN TWENTY-FOUR HOURS IN PERFORMING HIS DAILY CIRCUIT.

186. First.—The earth moves in its orbit sometimes slower and sometimes faster (§ 103). If it made no motion whatever in its orbit, the sun would seem fixed, like the stars; and, like them, would perform his daily circuit in 23 hours and 56 minutes (§ 116). The faster the earth moves in its orbit, the faster the sun seems to move eastward each day, and, consequently, the longer it is in reaching the meridian.

II.—183. What is the difference between natural and mean noon? On what days are they the same? What is the amount of difference on other days? 184. What is the equation of time? *Example.* 185. Why are not clocks and watches made to indicate natural noon? 186. *Explain the first reason for the inequality of the solar days.*

187. **Second.**—On account of the inclination of the earth's axis, the sun's apparent yearly path varies more or less from a direct eastward line. Fig. 23. p. 57, shows it inclining slightly toward the south above the horizon; some distance below the horizon (west), it inclines toward the north; while, in the horizon itself, it inclines neither way, but lies directly east, or parallel with the equinoctial.

Now, as we learned in the previous article, it is only the sun's *eastward progress* that delays the natural noon, and, if that progress is either north-east or south-east, of course *it* will not lengthen the day quite as much as if it were directly east. (*Man.* 62.)

188. *The two Causes combined.*—Thus we see that, if the earth's orbit around the sun were a perfect circle, so that the earth would always move at the same rate in that orbit, and if the axis were not inclined, so that the sun's apparent progress among the stars would be always directly east, viz., in the equinoctial, the natural days would all be exactly 24 hours long. But, in consequence of the two causes described above operating together, some of the days are more, and others less, than 24 hours in length.

Summary.—On account of the ellipticity of the earth's orbit and the inclination of its axis, the solar days are unequal in length. Clocks and watches do not follow these variations, but measure a day whose length is the *average* of the 365 solar days. The middle point, or noon, of this average day agrees with the middle point of the sun's course above the horizon only four times a year, the difference upon other days being the difference between "clock-time" and "sun-time," or the "equation of time."

Exercises.

1. Does the sun-dial indicate natural, or mean, noon?
2. Suppose that sun-time and clock-time agree to-day, but that, for the next month, the sun will make his daily circuits in just 24 hours and 20 seconds on an average; what will be the "equation of time" at the end of the month? (§ 184.)
3. Is the earth's motion in its orbit slower or faster than usual in January? (§ 103 and note at bottom of p. 65.)
4. Is the sun's apparent motion along the ecliptic nearly parallel with, or considerably inclined to, the equinoctial, in September? (§ 134 and § 187.)
5. What is the effect of each of these conditions *individually* upon the length of the solar day?

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187. *The second reason.* 188. *Under what conditions would the solar days be exactly equal? Give a brief summary of the whole subject.*

III.

THE PRECESSION OF THE EQUINOXES.

189. The Precession of the Equinoxes is the westward movement of the equinoxes along the ecliptic, at the rate of 1° in about 72 years.

190. *The Signs follow the Equinoxes.*—The vernal equinox is the starting-point, from which the signs of the zodiac, each 30° in length, are measured; and, as this starting-point is slowly moving westward (§ 189), of course the signs must be as slowly following; whereas the *constellations* of the zodiac, like the other constellations, remain stationary.

When the zodiac was arranged, about 2,100 years ago, the signs and constellations agreed in position.

Ex. 1. How far westward have the equinoxes and signs moved since then? *Ans.* Nearly 30° (2,100 ÷ 72).

2. With what constellation, then, does the sign Aries now correspond in position? *Ans.* Pisces (Fig. 22, p. 55. To move ♈ westward 30°, *depress* it one sign).

3. If the equinoxes move westward 1° in about 72 years, in about how many years will they complete their revolution around the ecliptic? *Ans.* Nearly 26,000 years.

191. Cause of the Precession of the Equinoxes.—Since the constellations and ecliptic are stationary, and since the equinoxes are merely the points in which the equinoctial crosses the ecliptic, their motion must be due to the motion of the equinoctial; and, since the equinoctial is nothing more than the earth's equator extended, the *real* motion must belong to the earth itself.

192. *The Motion of the Earth, which thus causes Precession,* is a "wabbling" motion similar to that of a spinning-top whose axis is inclined to the earth's surface, just as the earth's axis is inclined to the plane of the ecliptic. This peculiar motion of the earth is not only similar to that of the top, but its *causes* are also of the same nature.

III.—189. What is the precession of the equinoxes? 190. From what are the signs of the zodiac measured? Are these signs stationary in the heavens? Why not? Are the constellations of the zodiac stationary? Did the signs and constellations of the same name, ever coincide in position? Examples. 191. *To what does the real motion belong, which produces this westward movement of the equinoxes and signs?* 192. *Describe the real motion and explain its cause, illustrating with Fig.* 40.

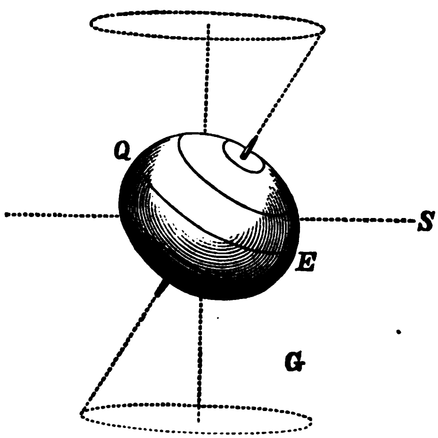

FIG. 40. *Revolution of Poles.*

Suppose Fig. 40 to represent a spinning-top of spheroidal form, like that of the earth, with its axis inclined from a perpendicular. The part next to E endeavors to fall toward G and drag the other parts after it; but, before it can reach the ground, it has spun round to Q. Every other part acts in the same manner, and the result is a revolution of the ends of the axis, represented by the dotted circles.

Now suppose the same figure to represent the earth—the line S showing the direction in which the sun lies. If the earth were a perfect sphere, the part E would be no more strongly attracted than the part directly under the sun; but, as there is an excess of matter at E, owing to the spheroidal form, the sun endeavors to draw this excess toward the line S. Before it can reach S, however, it has spun round to Q. All parts of the swelling around the equator being affected in the same way, the result is a revolution of the earth's poles in the dotted circles, 47° in diameter (2 × 23½), once in about 26,000 years.

193. *A Difference.*—While the axis of the top is drawn *from* the perpendicular, that of the earth is drawn *toward* the perpendicular. The motion of the axis in the two cases is, therefore, in *opposite* directions.

194. Change of the North Star.—As the axis of the celestial sphere is the earth's axis extended, the celestial poles slowly describe circles, 47° in diameter (2 × 23½°), around the poles of the ecliptic (Introd. § 28) once in 26,000 years. In half this time, therefore, the north pole of the heavens will be 47° distant from the present "north star," and another star* will perform the office of north star.†

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193. *A difference.* 194. Will the present north star always be thus distinguished?

* *Vega*, a bright star in the *Harp*.

† Several of the Pyramids of Egypt have tubular openings, all directed to a single point in the heavens, viz., the point which the star α *Draconis* (*Alpha of the Dragon*) occupied when on the meridian 4,000 years ago. At that time this star fulfilled the office of north star, and it is a most curious and interesting coïncidence that the date of the construction of the Pyramids corresponds almost exactly with that epoch. When the deductions of science and historical research thus harmonize, and both are confirmed—as it were, *by accident*—a peculiar satisfaction is felt, not only by the physicist and historian, but by every one who becomes acquainted with the facts.

195. Motion of the Equator, or Equinoctial.—As the axis slowly describes its circles upon the celestial sphere, the equator, or equinoctial, must slide around the ecliptic, carrying westward the equinoctial points, as above stated, about 1° in 72 years.

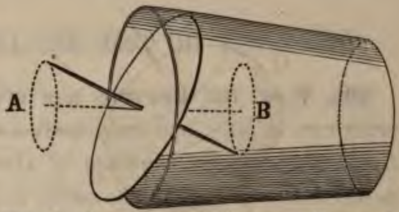

FIG. 41 *Precession of the Equinoxes illustrated.*

This may be illustrated as follows:

Cut a circular disk from cardboard for the plane of the equator, or equinoctial, and through its center pass a slender rod for the axis of the celestial sphere. Let the rim of a tumbler represent the ecliptic, and fit the card into it at an angle of 23½°. Now, if you cause the ends of the axis to describe circles, A and B, you will see the points in which the card meets the rim, move around the rim, as the equinoxes move around the ecliptic. Compare Fig. 41 with Fig. 22, p. 55. (*Man.* 63.)

OUTLINE OF ASTRONOMY.

In the preceding pages, we have studied the earth in its relations to other heavenly bodies. All the *general* knowledge we have obtained, we may apply, doubtless, to the other worlds that people space. Thus, we have, in reality, studied the Universe in one of its smallest members, as facts applying to the human race may be learned from a single individual.

In *details*, there is endless variety throughout the Universe, and it is the peculiar province of Astronomy, with the aid of the telescope, to present them to the student, so far as they may be determined. It should be understood in the very outset, however, that that portion of the Universe which the most powerful instruments bring within the range of our vision, is probably but as a mere drop in the ocean of infinity.

For the benefit of pupils who desire to learn something of other worlds disconnected from our own, but who have not opportunity for a more extended course, a few of the leading facts in regard to them are annexed.

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195. How does the gyration of the axis which has been explained, affect the equinoctial? *How may this effect be illustrated?*

IV.

DIVISION OF THE HOLLOW SPHERE OF THE HEAVENS.

196. How the Heavens are divided.—For the purpose of comparing the positions of the heavenly bodies with one another, and thus distinguishing them, the apparent surface of the heavens is divided by imaginary circles, as the real surface of the earth is divided by parallels and meridians. With several of these we are already familiar, viz., the *horizon*, the *meridian* (Introd. § 31 and § 33); the *equinoctial*, the *parallel circles* in which the heavenly bodies perform their apparent daily circuits (§ 91 and §94); and the *ecliptic* (§ 113).

There are three systems of celestial circles, viz., the *Horizon*, *Equinoctial*, and *Ecliptic* systems. Each of these has its *primary circle* and *secondary circles;* the first of which performs the same office that the equator performs in the division of the earth's surface, while the second correspond to the earth's parallels or meridians. Each also has its *measurements*, corresponding to latitude and longitude upon the earth's surface.

The Horizon system of circles moves with the spectator, while the other systems remain stationary.

197. The Horizon System.—The primary circle is the *horizon*. The poles are the *zenith* and *nadir*. The secondary circles pass through the poles perpendicularly to the horizon, and are called *verticals*. Among these, are the *meridian*, and the *prime vertical* which passes through the east and west points. (*Man.* 64.)

198. The Measurements are *altitude*, *zenith-distance*, *azimuth*, and *amplitude*.

Altitude is distance from the horizon toward the zenith, measured on a vertical.

IV.—196. How is the apparent surface of the celestial sphere divided, and for what purpose? Which of these circles have already been mentioned? Name the systems of circles used in the division of the heavens. What office do the primary circles perform? The secondary circles? How does the horizon system differ from the others? 197. What is the primary circle of the horizon system? The poles? The secondary circles? 198. What are the measurements? Define each.

Zenith-distance is distance from the zenith toward the horizon, measured on a vertical.

Azimuth is distance from the meridian toward the prime vertical, measured on the horizon, east or west.

Amplitude is distance from the prime vertical toward the meridian, measured on the horizon, north or south. (*Man.* 65.)

199. The Equinoctial System.—This is nothing more than the earth's poles, equator, parallels, and meridians, extended to the heavens.

The primary circle is the *equinoctial*, or *celestial equator*. The secondary circles are *declination parallels* and *right-ascension meridians*, corresponding to terrestrial parallels and meridians.

The two meridian circles passing through the equinoxes and solstices, are called the *colures*.

The *prime meridian* passes through the vernal equinox, as the terrestrial prime meridian passes through Greenwich (§ 30). (*Man.* 66.)

200. The Measurements are *declination*, *polar-distance*, and *right-ascension*.

Declination is distance north or south of the equinoctial, measured on a meridian.

Polar-distance is distance from the pole, measured on a meridian.

Right-ascension is distance east from the vernal equinox, measured on the equinoctial, as terrestrial longitude is measured from Greenwich, on the equator. It differs from terrestial longitude, however, in never being measured westward. (*Man.* 67.)

201. The Ecliptic System.—The primary circle is the *ecliptic*, whose poles are 23½° from the celestial poles. The secondary circles are *circles of celestial longitude and latitude*. (*Man.* 68.)

202. The Measurements are *celestial longitude* and *latitude*. The *former* is distance from the vernal equinox or prime meridian, measured on the ecliptic: the *latter* is distance from the ecliptic, measured on a circle of celestial longitude.

The measurements of the ecliptic system are less used than those of the equinoctial system.

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199. What is the primary circle of the equinoctial system? The secondary circles? To what do these correspond? What are the colures? 200. What are the measurements? Define each. 201. *What is the primary circle of the ecliptic system? The secondary circles? The measurements? Define each. What is said of these?*

V.

THE SOLAR SYSTEM.

203. The Solar System consists of the sun, and the various planets, meteoric bodies, and comets, which revolve around it.

The diameter of the space within which the solar system is included, is known to be more than 5 billions of miles. This does not include cometary orbits (§224).

204. The Sun's Mass is nearly 700 times that of all the other bodies of the solar system, taken collectively. Its diameter (§ 51) is 108 times that of the earth. Its gravity is so strong that an ordinary man would weigh about 2½ tons upon its surface.

205. Nature of the Sun.—The *spectroscope*, an instrument which reveals many of the substances of which a luminous body is composed, from the character of its light, proves that the sun contains iron, nickel, copper, zinc, and several other metals with which we are familiar. We, therefore, infer that its nature is *somewhat* like that of the planets which revolve around it.

Suppose the temperature of the earth were increased so as to equal that of the sun—the obvious results would be: (1) Increased volume and diminished density (§ 55); (2) All liquids and many solids would become gases, and hover around the planet as parts of its atmosphere; (3) The planet—atmosphere and all—would become intensely luminous. The latter is strikingly illustrated by a flash of lightning, which is probably mere air, moisture, etc., intensely heated by electricity. Suppose our whole atmosphere were thus treated—what would it be but a *photosphere* (sphere of light), like that surrounding the sun?

206. *Solar Spots, etc.*—The sun's surface, as seen through a telescope, is variegated with dark spots and brilliant points and streaks, called *faculae* (*little torches*).

A solar spot generally consists of a black *umbra* (*shadow*), surrounded by a lighter portion, called the *penumbra* (*partial shadow*). They are most numerous at intervals of about 11

V.—203. Of what does the solar system consist? *What is its extent?* 204. What is the sun's mass? Its diameter? Its force of gravity? 205. What is the spectroscope, and what does it prove in regard to the sun? What is the inference? *How might the earth be made to resemble the sun?* 206. How does the sun appear under the telescope? *Describe the solar spots, in regard to appearance;—number;—*

years. They occupy, chiefly, two zones, one on either side of the sun's equator, about 30° in breadth. Some of them are of immense extent, though they change in size and form, very much like little clouds in our sky. They revolve around the sun once in about 26 days, thus showing us the approximate time of the sun's rotation, and also the inclination of his axis to the ecliptic, $7\frac{1}{4}$°.

The spots are, without doubt, *vapors* condensed in the sun's photosphere, as clouds are formed in our atmosphere. These vapors, being less luminous than the photosphere, appear jet black in comparison, as a candle-flame appears a dark cone when seen against an electric light. Their density being increased by cooling, they must descend in currents or perhaps *showers*, toward the sun's center. This theory is confirmed by the fact that the spots are known to be below the surface.

The *faculae* are ridges of the photosphere often piled up about these darker clouds.

FIG. 42. *Movement of Solar Spots showing the Sun's Rotation.*

207. The Planets[1] may be distinguished from the fixed stars in two ways:

1. They move from constellation to constellation.
2. They shine with a steady light, and exhibit well-defined disks.

208. *General Facts regarding the Planets:*

1. They revolve around the sun in elliptical orbits.
2. They rotate from west to east.
3. Their orbits are slightly inclined to one another.
4. They shine by borrowed sun-light, and the nearest exhibit phases (§ 145) under the telescope.

position;—extent;—motion. What does the latter show? What is the nature of the spots? The faculae? 207. How may the planets be distinguished from the fixed stars? 208. State the general facts relating to the planets.

(1) Planet; *planetes,* a wanderer.

209. Tabular View of the Solar System.—The following table presents, in compact form, the principal elements of the solar system.

NAME.	Symbol.	Diameter in Miles.	Density. Water as 1.	Mean Distance from Sun.	Time of Revolution.	Time of Rotation.	Seasonal Variation.	Moons.	TELESCOPIC INDICATIONS.
The Sun.	☉	852,584	1⅓			25⅓ da.			(§ 206.)
The Moon.	☾	2,158	3⅓	(§48)	27⅓ da.	27⅓ "	Slight†		(Page 75.)
Mercury.	☿	2,962	7	35*	3 mo.	$24\frac{1}{12}$ hr.	Great.		Lofty Mountains upon its surface, Atmosphere.
Venus.	♀	7,510	5¼	66	7⅕ "	23⅓ "	Great.		Dense Atmosphere, Lofty Mountains.
Earth.	⊕	7,925	5⅔	91½	1 yr.	$23\frac{11}{12}$ "		1	
Mars.	♂	4,920	3	139	2 "	24½ "	Like ours.		Red Continents, Green Seas, Atmosphere, Ice and Snow.
Jupiter.	♃	88,390	1¼	476	12 "	10 "	Slight.	4	Dense Atmosphere, Cloudy Belts, Great Heat.
Saturn.	♄	71,904	⅔	872	29½ "	10½ "	Like ours.	8	Cloudy Atmosphere, Immense luminous Rings.
Uranus.	♅	33,024	1	1,754	84 "	9½ "	Very great.	4	
Neptune.	♆	36,620	1	2,746	164½ "	?	?	1	Some evidence of a Ring and a system of Moons.

210. ***Remarks on the Table.***—The *distances* of the various planets from the sun are computed from Kepler's third law: *The squares of their times of revolution are as the cubes of their solar distances.*‡

209. What is the sun's diameter? Name the largest planet. About how many times greater in diameter than the earth, is the latter? Name the smallest planet, not including the asteroids or moons. What planets are larger than the earth? Which are smaller? Which are more dense than the earth? Which are less dense? Name the planet most distant from the sun. The planet nearest the sun. Which are more distant from the sun than the earth? Which are nearer? In which planet is the year the longest? In which is the year the shortest? In which is the day the longest? In which is the day the shortest? In what planets is the seasonal variation greater than in the earth? In which is it less? What planets have moons, and how many have each? Upon what planets does the telescope reveal an atmosphere? Mountains? Cloudy belts? Rings? Ice and snow? What peculiarity in Mars? 210. How are the distances given in the table known?

* The numbers in this column indicate *millions* of miles.

† Compared with ours.

‡ Kepler's other laws are: 1. *The planets revolve in ellipses, with the sun in one focus.* 2. *Lines connecting the centers of the sun and planets, pass over equal spaces in equal times.*

Their distances being known, their *diameters* are found from their apparent diameters (§ 65).

Their comparative *densities* are calculated from the observed effect of their mutual gravitation (§ 2).

Their *times of revolution* are measured from their motions around the zodiac, allowance being made for the earth's motion.

Their *times of rotation* are measured from the movement of spots across their disks (Fig. 42).

Their *seasons* are known from the inclination of their axes to the planes of their orbits (§ 130).

The presence of *atmosphere* is inferred from the appearance of *clouds*, and also from that of *twilight* along their terminators (Fig. 11 and § 86).

Mountains are recognized by their *shadows.*

The *red light from Mars* is due to its dense atmosphere, which absorbs the other colors, as our own often does at sunrise and sunset. The polar regions of this planet appear quite white with ice and snow.

FIG. 43. *Jupiter, with his Belts and Moons.*

Jupiter's belts are exhibited in Fig. 43. His moons are thus named: *Io, Europa, Ganymede,* and *Callisto.**

Saturn's rings revolve in the plane of his equator. They differ greatly in

The diameters? The densities? The times of revolution? Of rotation? The seasonal variation? The presence of atmosphere? Of mountains? To what is the red light of Mars due? Name Jupiter's moons. *What important truth was discovered from these? (Note at bottom.)* What is said of Saturn's rings?

* It was from observations of Jupiter's moons, that Römer discovered the *speed of light,* in the year 1617 (§ 73). He noticed that the eclipses of the moons occur about 16 minutes earlier when Jupiter is nearest the earth, than when most distant, the difference in the distance being the diameter of the earth's orbit, 183,000,000 miles. The only way of accounting for this, is by supposing that it takes light 16 minutes to traverse this difference.

their breadth and brilliancy. The inner edge is about 19,000 miles, and the outer 48,000 miles, from the surface of the planet.

On account of the vast distances of *Uranus* and *Neptune*, but little is known of their physical features. The moons of Uranus, unlike all other members of the solar system, revolve from *east to west* in orbits whose planes are nearly *perpendicular to the plane of the ecliptic.*

FIG. 44. *Saturn, with his Rings and Moons.*

211. Asteroids.—Besides the planets named above, there is a numerous group between Mars and Jupiter, the members of which are generally less than 100 miles in diameter. These are called *asteroids*,[1] *planetoids*,[2] or *minor planets.*

They were, at first, supposed to be the fragments of an exploded planet, which was thought to be needed to fill a vacancy between Mars and Jupiter; but this theory has since been abandoned, although there seems to be a mysterious connection among them, from the fact that, if their orbits were so many material rings, no one could be disentangled from the rest.

The four, first discovered, received the following names and symbols: *Ceres* ⚳, *Pallas* ⚴, *Juno* ⚵, and *Vesta* ⚶. Those since discovered, 114 in number (1871), have classical names; but their symbols are simply circles, enclosing the numbers denoting the order of their discovery. Thus, *Virginia* (50) is the 50th asteroid in the order of discovery.

The asteroids differ from the other planets not only in their inferior size, but also (in many cases) in the great inclination of their orbits to the ecliptic. Their average distance from the sun is 245 million miles. (*Man.* 70 and 71.)

Of Uranus and Neptune? 211. What are the diameters of the asteroids? What other names have they? *What were they supposed to be? What mysterious fact in regard to their orbits? What four asteroids were first discovered? How many have been discovered since? How are they designated? How do they differ from the larger planets?*

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(1) Asteroid; from two Greek words meaning star-formed.

(2) Planetoid; from two Greek words meaning planet-formed.

THE PLANETS ARE GROUPED IN TWO DIFFERENT WAYS.

212. *First*, in three groups: (1) *Interior planets*, those comparatively near the sun, including Mars; (2) *Asteroids;* (3) *Exterior planets*, those comparatively distant from the sun.

The interior planets are much smaller, though of greater density, than the exterior planets; move more swiftly in their orbits (thus counteracting the effect of the sun's more powerful attraction); and, with the exception of the earth, have no moons.

The exterior planets rotate the most rapidly, and are the most flattened at the poles (§ 18).

213. *Secondly*, in two groups: (1) *Inferior planets*, nearer the sun than the earth; (2) *Superior planets*, more distant from the sun than the earth.

The inferior planets are said to be in *inferior conjunction*, when they come between the earth and sun; and in *superior conjunction*, when the sun is between them and the earth. Sometimes, when they are in inferior conjunction, they pass *exactly* between us and the sun, when they are seen as little, round, black spots passing over the sun's disk. These events are called their *transits (crossings)*. Their greatest apparent distances from the sun are called their *greatest eastern* and *western elongations*. These must be less than 90°, else the inferior planets would be as far or farther from the sun than the earth. (*Man.* 73.)

The superior planets can, of course, never be in inferior conjunction. They are said to be in *conjunction*, when the sun is between them and the earth; and in *opposition*, when the earth is between them and the sun. (*Man.* 75.)

214. Morning and Evening Stars.—When the planets appear in the east before sunrise, they are called *morning stars;* when in the west after sunset, *evening stars.*

The inferior planets are morning stars, while moving from superior to inferior conjunction; and the superior planets, while approaching conjunction. The inferior planets are evening stars from inferior to superior conjunction; and the superior planets, while moving from conjunction. (*Man.* 74 *and* 76.)

215. Direct and Retrograde Motions of the Planets.—Direct, or forward,

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212. Describe the first method of grouping the planets. *How do the interior planets differ from the exterior?* 213. Describe the second method of grouping the planets. *When are the inferior planets in inferior conjunction? In superior conjunction? When are they in transit? What are their greatest elongations? Can these be greater than, or equal to, 90°? What is said of the conjunction of the superior planets? Opposition?* 214. Explain morning and evening stars. *When are the inferior planets morning, and when evening, stars? The superior planets?* 215. What is meant by direct and retrograde motion?

motion is from west to east, or in the order of the signs of the zodiac. Retrograde motion is the opposite. Thus, motion from Aries into Taurus would be direct; from Taurus into Aries, retrograde.

To an observer upon the sun, the motions of the planets would be uniformly direct; as seen from the earth, however, they are sometimes retrograde. (*Man*. 72.)

216. *The Cause of the Retrograde Motions* of both inferior and superior planets, can best be understood by extending the experiment described on page 58. Let several persons describe orbits around the tree, some nearer and others more distant than yourself. The former, as seen against the horizon, will seem to move backward and forward, like pendulums. The latter will seem to move backward for a moment or two occasionally, and forward for the rest of the time, the cause for which will be evident.

The conjunctions and oppositions of the planets, morning and evening stars, etc., may be very clearly illustrated in the same way.

217. Discovery of the Planets.—All, excepting Uranus, Neptune, and the asteroids,—being visible to the naked eye,—were known to the ancients.

218. *Uranus* was discovered in 1781, by Sir William Herschel.

219. *Neptune* made its existence known by *its effects upon Uranus*. It was observed to *draw it out* of the orbit which it ought to describe, supposing no other planet beyond it. In 1845, Leverrier calculated *just where in the heavens and of what apparent size* a planet ought to be, to produce the observed effect upon Uranus. The telescope proved his calculation correct. *There was Neptune in the spot specified*—not an accidental discovery, as the other planets had been, but one of the proudest trophies of scientific skill on record.

220. *The Asteroids.*—Shortly after the discovery of Uranus, the first four asteroids were discovered by an association formed for the purpose of looking for the supposed planet between Mars and Jupiter. Since then, many others (§ 211) have been added to the list, and there is every reason to believe that there are thousands of these miniature worlds circling around the sun.

Do the planets ever retrograde, as seen from the sun? From the earth? 216. *How may the cause of their retrogradations be illustrated?* 217. What planets were known to the ancients? 218. When, and by whom, was Uranus discovered? 219. How, when, and by whom, was Neptune discovered? 220. The first four asteroids? What is supposed to be their actual number?

221. Meteoric Bodies.—The asteroids are not the smallest bodies flying around the sun. It would seem, almost, as if there were a regular gradation from Jupiter down to the merest atom. The earth frequently ploughs through the orbits of multitudes of tiny members of the solar system, some of which are no bigger than a walnut, while others weigh several tons. Yielding to the earth's superior attraction, they fall to its surface; and, in their rapid descent through the atmosphere, they become greatly heated, and fall as "*meteors*," or balls of fire; as "*shooting stars*," or vanishing streams of light; and, sometimes, as "*aërolites*," or solid masses of stone.

Many wonderful accounts are on record of meteoric showers, which are observed to occur with greater or less brilliancy at certain intervals. This has given rise to the belief that these bodies exist most abundantly in vast streams which revolve about the sun, somewhat after the manner of the group of the asteroids; and that, in August and November, when star-showers are most common, the earth passes through portions of these streams.

222. Comets (*hairy bodies*), are especially interesting on account of (1) their wonderful appearance, and (2) their peculiar movements.

223. *Appearance.*—They assume a great variety of forms, of which the most familiar is a star-like head, or *nucleus*, surrounded by a cloudy envelope, the *coma*, to which is attached a long, shining *tail*, generally stretching in a direction *from* the sun.

224. *Their Orbits.*—The direction, dimensions, and form of their orbits may be found from observations of the small portions through which we see them move, somewhat as the circumference and plane of a circle may be found from a small arc of the circle. It has been found that their orbits assume three different forms, illustrated below.

A comet moving in an *ellipse* (1. Fig. 45) returns at regular intervals varying from a few years to many centuries; one moving in a *parabola* (2) or *hyperbola* (3), having once made its appearance, will never revisit our system, but will move on into infinite space, until some new attraction changes the form of its orbit.

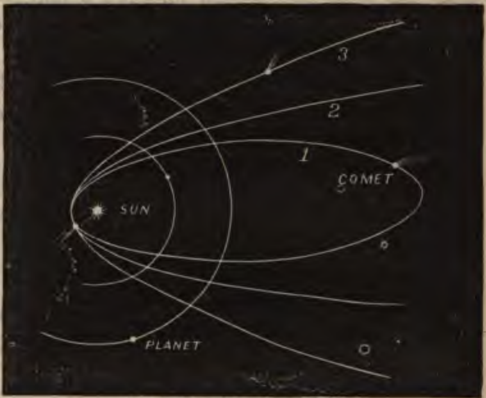

FIG. 45. *Cometary Orbits.*

225. *Number and Density.*—Although but few are seen by the naked eye, they doubtless exist by millions. As the most magnificent comets have never been seen to affect any other body, while they themselves are *powerfully* affected by the smallest planet, we know that the amount of matter which they contain must be exceedingly small. In fact, it is thought that our earth *has even passed through a comet's tail*, without our knowing it.

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221. *What is said of the size of meteoric bodies? Why do they fall to the earth? How are they classified? What theory accounts for periodical star-showers?* 222. Why are comets especially interesting? 223. *Describe their appearance.* 224. *How may the direction, dimensions, etc. of their orbits be found? What comets "return" at regular intervals? What comets never return?* 225. *What is said of their number? Their density.*

226. *Among the most remarkable Comets* which have been observed are: *Halley's*, the first whose orbit and period of revolution (75 years) were calculated; *Encke's*, with a period of $3\frac{1}{3}$ years; *Biela's*, of $6\frac{3}{4}$ years; *those of* 1680 *and* 1843, which came very near the sun; *that of* 1811, remarkable for having been visible for several months, and for having a wide-spreading tail; *Donati's*, with a period of about 2,100 years; and *that of* 1861, whose splendor some of us may remember.

227. The Zodiacal Light is a faint glow that sometimes extends to a considerable height above the horizon, below which the sun is shining. It generally assumes a triangular form, and is supposed to be an immense ring of nebulous matter surrounding the sun.

VI.

THE FIXED STARS.

We began our study of Astronomy with a single planet; we then extended it to an entire system; we will now turn our attention to those other systems, whose suns twinkle upon us from the night sky, at such immense distances that they present the same appearances, whether viewed from the earth or from the most distant planet of the solar system (§ 50).

228. How is it known that the Stars are Suns?—In order to be visible at such inconceivable distances, many of them *must*, *of necessity*, be much larger and brighter than our own sun.

229. *Their Number.*—With the naked eye, only about 6,000 are visible; those visible under the telescope are innumerable; and their whole number is, doubtless, absolutely infinite.

230. *Magnitudes.*—They are divided by astronomers into classes, according to their brightness. The brightest, of which there are about 20, are called stars of the *first magnitude*. The next brightest—about 60—are of the *second magnitude*, etc. Stars below the sixth magnitude are invisible to the naked eye.

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226. *Name some of the most remarkable comets which have been observed.* 227. *What is the zodiacal light?*

VI.—*What forms would the constellations assume, if we could view them from the most distant planet of our system?* 228. How are the stars known to be suns? 229. What is said of their number? 230. Magnitudes?

"Magnitude," in this sense, does not refer to their real size, nor even to their apparent size, for none of them have any apparent diameter whatever. The finest spider-thread in the focus of the telescope will completely hide the brightest from view. They differ only in the *intensity*, or *brightness*, of their rays, and this difference is due, not only to differences in real splendor, but to differences in distance.

231. The Scintillation, or twinkling, of the fixed stars is due to what is termed the "*interference of light*" in our atmosphere. The same appearance would be produced, if a *single ray* should penetrate the atmosphere from a mere *point* very near us. The planets do not twinkle, because they present more than mere points to our view.

232. The Stars are in Motion, describing immense orbits around one or more centers of gravitation, and requiring millions of years to complete their revolutions. Our sun is supposed to be moving, with other stars, around *Alcyone*, one of the *Pleiades*, having a period of about 18 *millions of years*.

233. *How is the Motion of our System known?*—If you walk in a lane leading through a forest, you will observe that trees in front of you seem to separate, as you approach them, while trees behind you seem to close together. In comparing the positions of the stars, as laid down in the catalogues of the ancients, with their positions to-day, we observe that the stars of a certain constellation, *Hercules*, have *perceptibly separated*, while those in the opposite part of the heavens, have *as perceptibly approached one another*. This satisfies us that our whole system is in motion toward Hercules.

234. The Constellations.—The ancients, who seem to have been much more imaginative than the moderns, saw in the arrangement of the stars the shadowy forms of men, animals, and other objects, grouped in the most promiscuous and meaningless manner. There was, among their astronomers, a curious admixture of patient and accurate observation with the grossest superstition. The division of the stars into constellations was made by them with a two-fold object; *first*, to give their forms of religion a visible foundation; and, *secondly*, to enable them to distinguish one star from another, and to compare observations made at different times.

235. *The Chief Uses of a Knowledge of the Constellations and their Positions.*—1. The navigator or land traveler can read at once his exact position on the earth's surface. 2. We can observe the motions of the planets and comets in the celestial sphere, without being confused by the earth's daily rotation. 3. We may know at once where to look, whenever we learn

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231. *Explain their twinkling.* 232. Are the stars in reality "fixed"? The sun? 233. *How is the motion of the latter known?* 234. Who arranged the stars in constellations? With what object? 235. *What advantages result from an acquaintance with the constellations.*

of any new discovery, or, if any marked change should take place in the heavens, we may ourselves, be among the first to observe it. And, certainly, the refined satisfaction of seeing, night after night and year after year, the inevitable return of well known figures in the starry heavens, instead of an undistinguishable maze, is ample reward for the most patient effort.

236. The Constellations may be divided into three Classes.—1. Those north of the zodiac. 2. Those of the zodiac. 3. Those south of the zodiac. The forms and positions of the constellations are best learned from a celestial globe, atlas, or planisphere.*

PRINCIPAL CONSTELLATIONS NORTH OF THE ZODIAC.

Name.	*Brightest Stars.*
Andromeda,	Alpheratz, Mirach.
Aquila, *the Eagle,*	Altair, Alshain.
Auriga, *the Wagoner,*	Capella, Menkalinan.
Boötes, *the Bear-driver,*	Arcturus, Nekhar.
Cassiopeia,	Schedir, Caph.
Camelopardalis, *the Camelopard,*	Alderamin, Alphirk.
Cepheus,	Gemma, Alphecca.
Coma Berenices, *Berenice's Hair,*	
Cygnus, *the Swan,*	Arided, Deneb Adige.
Draco, *the Dragon,*	Thuban, Alwaid.
Hercules,	Ras Algethi.
Lyra, *the Harp,*	Vega, Sheliak.
Ophiucus, *the Serpent-bearer,*	Ras al Ague.
Pegasus, *the Flying Horse,*	Markab, Sheat, Algenib.
Perseus,	Mirfak, Algol.
Vulpecula, *the Fox and Goose,*	
Ursa Major, *the Great Bear,*	Dubhe, Mirak, Phecda.
Ursa Minor, *the Little Bear,*	Polaris, Kocab.

236. How may they be classified? *Name some of those north of the zodiac. Those of the zodiac.*

* The author has prepared a set of two wall maps, exhibiting the Northern and Southern Hemispheres. These are designed to be used in the school-room, as the sky itself is studied at night. Accordingly, the names of the stars, the guiding lines, etc., are so faintly traced, as to be invisible at a little distance. These maps serve a purpose similar to that of Geographical Outline Maps, and are accompanied by a Key for the use of pupils in preparation for exercises upon the maps.

CONSTELLATIONS OF THE ZODIAC.

Name.	*Brightest Stars.*
Aries, *the Ram,*	Hamal, Sheratain.
Taurus, *the Bull,*	Aldebaran, Nath.
Gemini, *the Twins,*	Castor, Pollux.
Cancer, *the Crab,*	Al Hamarein.
Leo, *the Lion,*	Regulus, Denebola.
Virgo, *the Virgin,*	Spica, Zavijava.
Libra, *the Balance,*	Phact.
Scorpio, *the Scorpion,*	Antares, Akrab.
Sagittarius, *the Archer,*	Alpha, Kaus.
Capricornus, *the Goat,*	Deneb Algedi.
Aquarius, *the Waterbearer,*	Sadalmelik.
Pisces, *the Fishes,*	Kaïtaïn.

PRINCIPAL CONSTELLATIONS SOUTH OF THE ZODIAC.

Name.	*Brightest Stars.*
Argo, *the Ship Argo,*	Canopus, Tureis.
Canis Major, *the Great Dog,*	Sirius, Mirzam, Wesen.
Canis Minor, *the Little Dog,*	Procyon, Gomeisa, Isis.
Cetus, *the Whale,*	Menkar, Diphda, Mira.
Centaurus, *the Centaur.*	
Crux Australis, *the Southern Cross.*	
Eridanus, *the River Po,*	Achernai, Cursa.
Hydra, *the Water-serpent,*	Alphard.
Piscis Australis, *the Southern Fish,*	Fomalhaut.
Monoceros, *the Unicorn.*	
Orion, *the Hunter,*	Betelgeuse, Rigel, Bellatrix.

7. How the Stars are named.—Many bright stars have proper names; as *ris*, the north star; *Sirius*, the Dog-star; but, generally, they are desig-d by the letters of the Greek alphabet. Thus, *α Centauri* (*Alpha of the aur*) is the brightest star in *Centaurus*; *β Leonis* (*Beta of the Lion*) is rightest star, but one, in the *Lion*, etc

8. Stars of different Kinds.—The telescope reveals many wonderful dif-ces among the stars. The principal varieties are enumerated below.

. *Double, triple, and multiple Stars.*—Several thousand stars, which to the naked eye r single, are seen, under the telescope, to consist of two, three, or more stars revolving

th of the zodiac. 237. How are the stars named? 238. Do they differ in magnitude 239. *What is said of double, triple, and multiple stars?*

in ellipses around a common focus, with periods varying from a few years to several centuries.

240. *Colored Stars.*—Some stars are white, like our sun; others are red, yellow, or blue. In fact, almost every variety of color is displayed in the heavens.

241. *Variable Stars* are those whose brightness changes periodically. The most noticeable of these are *Mira* (the wonderful) in the *Whale*, and *Algol* in *Perseus*. The cause of their variations is not definitely understood; but they are supposed to be due to the revolution of huge planets or nebulous (cloudy) matter around the stars.

242. *Temporary Stars* are such as have suddenly made their appearance in the sky, and gradually vanished, without having since reappeared. Numerous such instances are on record. There are some stars now visible, which were not seen by the ancients, and others which are styled *lost stars*, among which the "*lost Pleiad*" is a famous example. Whether these are really created and destroyed, or whether they are only variable stars with periods immensely long, is not known.

243. *Starry Clusters* are groups of stars which appear more closely collected than the stars generally. The *Pleiades*, and *Berenice's Hair*, are well known examples. They are generally most crowded in the center, and, in some cases, constitute *systems of systems* by themselves. The *Galaxy*, or *Milky Way*, is a starry cluster entirely encircling the heavens. To the naked eye, it appears a mere haze flowing through the sky like a river of soft light, but the telescope shows it to consist of millions of stars, of which our sun is supposed to be one.

244. *Nebulæ* (clouds) are certain misty collections scattered, here and there, through the heavens, which differ from starry clusters in that the most powerful telescopes fail to resolve them into separate stars. They may consist of stars which are too distant to be thus resolved, or they may be in reality, what they appear, masses of cloudy matter diffused through immense spaces.

245. The Nebular Hypothesis teaches—(1) that all matter originally existed in the form last described; (2) that, as the dispersive power of heat was superseded by the collective power of gravitation, planets and suns gradually came into existence; (3) that the immense *amount of motion*, or *momentum*, thus produced, still exists in the rotations and revolutions of the heavenly bodies. Something like this theory was advanced in treating of the Form of the Earth, page 17.

246. Is the Universe a Desert?—We see on several of the nearest planets, evident preparations for the residence of intelligent beings (§ 209). As there are vast differences in the intensity of the natural forces (light, heat,

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240. *Of colored stars?* 241. *Of variable stars?* 242. *Of temporary stars?* 243. *Of starry clusters?* 244. *Of nebulæ?* 245. What is the nebular hypothesis? 246. What reasons have we for believing that other planets are inhabited? Could *we* live upon other planets, as we are at present constituted?

and gravity) in the different planets, their inhabitants—if any exist—must differ widely in their requirements.

It is not likely that *all* the planets are inhabited at the present time. There was a long series of ages in the history of the earth, when no living thing existed upon its surface. Other worlds are, doubtless, in the same condition to-day; indeed, we are taught that perfect desolation will revisit the earth. But, that the larger planets, at least, were designed to be at some time or other the scenes of intelligent life, is by no means improbable.

The Creator has revealed to us, in his works, a general unity of plan. Everywhere around us, we see evidences that He delights in life and happiness. The air is peopled with myriads of joyous creatures; the heart of the forest, the mountain stream, the depth of the sea, the very soil beneath our feet, each teems with its breathing millions, and even the frozen pole was deemed worthy of a tenant. So, although beings like ourselves might not be able to exist in any other planet than our own, we may yet believe that it is not inanimate nature alone that obeys the mandate—

"Praise Him, all ye stars of light."

EXERCISES ON SUPPLEMENT.

I.—1. Suppose a balloon should start from New York at noon, Jan. 1st, and move westward as fast as the sun seems to move, until it came round to New York again; would the aëronaut witness sunset, night, and morning?—2. Then, if he reckoned the days by the sun, what date would it still be *to him*?—3. What would be the date, however, at New York?—4. What must he do, during his journey, to preserve the true date? (p. 88, note at bottom.)

II.—5. What is the difference between sun-time and clock-time on the 27th of October? (Consult an Almanac, or the dial of the Tellurian.)—6. What is the equation of time on that day?—7. Is the sun fast, or slow?—8. At what o'clock will he reach the meridian?

III.—9. In how many years will the vernal equinox be in constellation *Virgo*, opposite its present position? (§ 190.)—10. What will then be the north star? (p. 92, note at bottom.)

IV.—11. A star is 30° above the horizon, and 20° south of the north point; what is its *altitude; zenith-distance; azimuth; amplitude*?—12. A star is over the tropic of Cancer, and 50° east of the vernal equinox; what is its *declination; polar-distance; right-ascension*?—13. What is the sun's *celestial longitude* at the autumnal equinox?

V.—14. A solar spot occupies $\frac{1}{40}$ the diameter of the sun's disk; what is its diameter in miles? —15. In 1870, a bright "star" appeared in constellation *Scorpio;* in 1871, in constellation *Sagittarius;* was it a *star*?*—16. How many hours from sunrise to noon in Jupiter? In the moon? (§ 209.) —17. How long is each season in Mercury? In Saturn? (§ 209.)—18. Name the *interior* planets; *exterior; inferior; superior*.—19. What name is applied to a *transit* of the moon? (§ 213.)—20. A planet moves from *Leo* into *Virgo;* is its motion *direct*, or *retrograde*?—21. A bright body is seen to approach very near the sun, then move almost directly north, until, in a few days, it becomes invisible. In a few years it will appear again. What is it?

VI.—22. Name all the differences you can between a star and a planet.—23. Is the sun a star? A *fixed* star? Why not?—24. How does it probably appear, as seen from the other stars?—25. If its diameter were equal to that of the earth's entire orbit, how would it appear from the nearest fixed star? *Ans.* It would present an apparent diameter equal to the *annual parallax* of the star, with the diameter of the earth's orbit as a base line, viz., about 2″, that is, it would appear as large as a silver dime, seen at the distance of a mile!

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* Saturn.

MANUAL

OF

DIRECTION FOR THE USE

OF

THE STELLAR TELLURIAN.

INTRODUCTION.

ALL departments of Natural Science are learned at an immense disadvantage from ɜre verbal description. This is especially true with regard to the young, who fre- ently comprehend at a glance from "ocular demonstration," what hours of labored planation would fail to make plain to them.

Hence, the most successful teachers are those who, other things being equal, are ›st fertile in expedients for illustration. They seize upon every opportunity to ıke the eye aid the imagination and understanding. But the ordinary resources of › school-room are wholly inadequate to the proper illustration of Astronomy and branch, Mathematical Geography. A terrestrial globe, properly mounted and llfully used, will explain many things otherwise unintelligible to the ordinary pu- ; but even this will go but little way in presenting those *combinations* which con- ɹute the real difficulties of the science.

Accordingly, it was thought that the objects of the foregoing treatise would be ch more effectively accomplished, if it were reïnforced by the best *mechanical ap- ances* that could be procured.

The choice fell upon the "Stellar Tellurian," which seemed the most complete and t adapted to the purpose of any to be procured, inasmuch as its exhibits, not only sun, earth, and moon with the proper motions, but also the celestial sphere sur- ınding these bodies, and, especially, the *zodiac and ecliptic plane*—without which illustrations would be very incomplete and unsatisfactory. At the author's re- ɜst, the manufacturers made several changes in this apparatus, thereby adapting it the illustration of a range of topics not usually compassed by a mere "Tellurian" trument. Among these topics may be mentioned—Precession of the Equinoxes o. XVIII); Division of Celestial Sphere (No. XIX); Solar System (No. XX); re Occurrence of Eclipses (Illust. 50); and, in short, all requiring the use of the all globe represented in Fig. C, p. 6.

It is true, no idea of relative distance or magnitude is conveyed by the apparatus, ˙ is such office claimed for it, any more than it is claimed for the diagrams, etc., ich abound in every treatise on this subject. Pupils must be made to understand

that it teaches only the *motions* and their *results*—the only department that requires apparatus. For comparative distances, magnitudes, and all other matters, they must look elsewhere. The scale on page 10, is inserted to supply this deficiency, so far as it is possible to supply it.

Some teachers object to apparatus for teaching Astronomy and Mathematical Geography, because the pupil is liable to retain in his mind the *apparatus* rather than the *reality*. Precisely the same objection may be urged against *maps* and ordinary *globes*. What pupil thinks of South America, save as a parti-colored triangle upon a page of his atlas? yet who would think, for a moment, of teaching Geography *without maps*? In both cases, the teacher has the same labor to perform—constantly to divert the attention of his pupils from the representation to the reality; and, in after years if not before, map and apparatus—both indelibly fixed in the memory—will fulfill their true office of aiding the imagination to comprehend the great realities which they represent, and which, *without them*, would, in many cases, *never* be understood.

Moreover, every teacher *uses apparatus*, whatever his objections may be, and the only question is—which are preferable, the apples, bells, inkstands, etc., which usually serve for earth, sun, and moon, *or the results of the inventor's best skill?*

DESCRIPTION OF THE APPARATUS.

THE Stellar Tellurian was patented by Dr. S. P. Campbell July 16, 1867; and by George S. McKenzie August 28, 1871. Its most important features are exhibited in the accompanying engravings:

Fig. A shows the circular iron case which contains the mechanism for rotating the terrestrial globe 30 times a month, as indicated by the dial,—moving it in an *elliptical* orbit,—preserving the "parallelism of the axis,"—and also for the 13+ sidereal and 12+ synodic revolutions of the lunar globe. In the focus of the ellipse, is a gas-burner (or lamp) to represent the sun. Over this is fitted a ground-glass globe, the effect of which is, not only to suggest the appearance of the sun, but also to *diffuse* the light, and thus cause the circle of illumination, or *terminator*, to appear of the proper magnitude upon the terrestrial globe.

Upon the dial are readings for the months, signs and constellations of the zodiac, equinoctial and solstitial points, perihelion and aphelion, the equation of time, together with the diameters of earth, sun, and moon, and a circle bearing the same proportion to the circumference of the instrument, that the earth's circumference bears to that of the sun.

A brass meridian and day-circle are appended to the terrestrial globe, which may be substituted for the effects of the artificial light.

In Fig. B, are shown those parts which represent the plane of the earth's orbit, or ecliptic, continued beyond the orbit itself and cutting the celestial sphere in the mid-

dle of the zodiac. These parts are placed above the base shown in Fig. A, and thus the zodiac is correctly represented as a *belt* of the heavens encircling the earth and sun, rather than as a flat ring below. The great advantage of this arrangement, for illustrating the apparent motions of the sun and moon through the twelve signs of the zodiac, is seen at a glance.

FIG. A.

Upon the outside of the hoop are represented the stars of the zodiac in their relative positions, with sections of the "Milky Way" and equinoctial; while, upon the inside the orbits of the planets, an asteroid, and a comet, from ascending to descending node, are shown, with a table of distances and magnitudes.

Within the "zodiac," and resting on the "plane of the ecliptic," are two graduated semi-circles attached at the equinoctial and solstitial points. These may be raised at different angles to describe the half of the celestial sphere north of the ecliptic, and to represent the equinoctial, the colures, the north celestial pole, right-ascension and declination, etc.

When the celestial sphere is illustrated in this manner, of course the earth and its

FIG. B.

orbit must occupy as small a space as practicable in the center. Accordingly, a small representation of the earth is added to the apparatus, which may be placed upon the gas-burner in the center, in the manner shown in Fig. C.

FIG. C.

The earth is otherwise represented by two globes, one mapped and the other slated. Most teachers will find more use for the latter than the former. The reflection from it will, of course, be much stronger, and the boundary between day and night more distinctly defined, if its surface is *whitened* with chalk, when the artificial light is used. It will also be found that better results can be obtained with a small, tapering flame, than with a large, flaring one. In fact, the lower the flame—to a certain limit—the more sharply cut the shadows will be.

Of the two other small globes, the larger is still another representation of the earth, and the smaller, of the moon. Their special use is explained in the Manual, Illustration 50.

MANUAL.

[The style adopted in the following Illustrations, is designed to admit of their being read simultaneously with the manipulation of the Apparatus. It is suggested that, while one pupil reads the Illustrations aloud, another handle the Apparatus according to the directions given, with such aid from the teacher as may be necessary. After an Illustration is thoroughly understood, the imagination should be directed, *in every instance*, to the reality in the earth or sky.

The directions in brackets refer to those parts of the Mathematical Geography to which the Illustrations apply, although, of course, the latter are equally applicable to any treatise on Astronomy.]

I.—FORM OF THE EARTH.

[Sec. I.—Chap. I and II.]

Illustration 1.—The General Form of the Earth is represented by this slated globe. The roughness of its surface corresponds to the general unevenness of the earth's surface, and affects its spherical form nearly as much.

2. Mountains might be represented by grains of sand scattered, here and there, upon the surface of this globe; while a fine thread would amply represent a mountain-chain.

3. The Ocean.—If a moist brush or sponge be lightly passed over any considerable part of the surface of this globe, the moisture will be sufficiently deep to represent the ocean.

4. The Atmosphere is estimated to extend about 50 miles from the earth's surface—a distance equal to about $\frac{1}{160}$ of its diameter. Hence, a covering, $\frac{1}{160}$ of the diameter of this globe, or about $\frac{1}{27}$ of an inch in thickness* (for example, an envelope of thin cloth tightly fitting the globe), would not be

* Whenever the dimensions of any part of the apparatus are given, the *larger size*, with a globe 6 inches in diameter, is referred to. The smaller size has a 3-inch globe.

greatly out of proportion, as far as *thickness* is concerned, to represent the atmosphere enveloping the earth.

5. Spheroidal Form of the Earth.—If points be marked upon the surface of this globe from its equator to its poles, and the globe be rotated, it will be seen that a point exactly upon either pole will not change its place, but will simply turn upon its own center; while the other points will move with different degrees of speed, according to their distance from the pole. Hence, those parts of the globe through which the equator passes, are influenced in the greatest degree by *centrifugal force*, and, if the material were sufficiently yielding, this rotation would force the globe perceptibly into the form of an *oblate spheroid.*

6. The Amount of Depression.—Each pole of the earth is depressed an amount equal to about $\frac{1}{600}$ of the whole diameter. If, then, a piece of sand-paper be rubbed gently a few times over the poles of this globe, the proportionate amount of flattening will be produced.

II.—LATITUDE AND LONGITUDE.

[Sec. II.—Chap. I.]

Illustration 7.—Circles and Points fixed by the Earth's Rotation.—This globe, in its present motionless state, has neither axis nor equator. If, however, we rotate it so that points upon its surface describe horizontal circles, an *axis* is at once established in a vertical direction. If the circles of rotation now become vertical, the axis will be horizontal. If we hold a crayon against a point midway between the poles, while the globe rotates, the *equator* will be described; at other points, other *parallels* will be drawn. Drawing the crayon from pole to pole across the parallels, we describe a *meridian;* completing the circle, we have a *meridian circle* drawn.

It is evident to the eye, that the meridians are all of equal length; while the parallels diminish from the equator to the poles.

8. Latitude and Longitude.—This point (north pole) is in lat. 90° north. Points upon this parallel (midway between the pole and equator) are in lat. 45° north,—upon this, 45° south. Points upon this circle have no latitude.

We may select any meridian to represent the *prime meridian.* If we

elect, for example, the one first drawn, points upon the opposite meridian will be in long. 180° east or west. This point (90° to the *right* of the prime meridian), will be in long. 90° east; and this, in long. 90° west.

To determine the position of a place upon the earth, we must know both its latitude and longitude. Thus, a place in lat. 45° north, may lie anywhere on this parallel; one in long. 90° east, may lie anywhere on this meridian; but one in both lat. 45° north, and long. 90° east, can be only at this particular point, where the two circles intersect each other.

III.—ZONES.

[Sec. I.—Chap. II.]

Illustration 9.—The Torrid Zone.—This elevated plane (Fig. B) shows the direction of those rays which strike the earth vertically at different seasons of the year. Now, if we rest a crayon upon this plane, and apply it to the globe just where the vertical rays strike, and, at the same time, cause the globe to perform a complete revolution around the sun (*glass globe*), we shall see the *torrid zone* drawn upon the globe—as it were, by the sun's vertical rays.

10. The Frigid Zones.—If the crayon be applied where the most oblique northern rays fall, and the revolution be produced as before, the *north frigid zone* will be drawn upon the globe. (*To guide the crayon, either affix the brass day-circle or use the artificial light; then keep the crayon steadily at that point of the day-circle which is nearest the pole.*) The *south frigid zone* will, of course, be the corresponding space around the south pole.

11. The Temperate Zones.—The unmarked portion, between the torrid and north frigid zones, will represent the *north temperate zone*, with its breadth of 47°—the *south temperate zone* occupying the corresponding space south of the equator.

IV.—MAGNITUDES AND DISTANCES.

[Sec. II.—Chap. III.]

No apparatus can correctly represent the immense distances which intervene between the heavenly bodies. Nor is it practicable to represent, by such means, even their comparative

magnitudes. As announced in the Introduction to the Manual, a page is here introduced to supply, as far as possible, a deficiency which pertains not only to apparatus, but also to the diagrams and other pictorial illustrations which are presented to every student of astronomy.

SCALE OF COMPARATIVE MAGNITUDES AND DISTANCES. (*Herschel.*)—Let a globe, 2 feet in diameter, be placed in the center of a wide plain for the Sun.

The planet Mercury will then be represented by a mustard seed 82 feet distant from the globe.

Venus, by a pea 142 ft. distant.

The Earth, by a pea 215 ft. distant.

Mars, by a pepper-corn 327 ft. distant.

Asteroids, by grains of sand from 500 to 600 ft. distant.

Jupiter, by an orange ¼ mile distant.

Saturn, by a small orange ⅖ mile distant.

Uranus, by a cherry ¾ mile distant.

Neptune, by a plum 1¼ miles distant.

The nearest Star, by another globe similar to that representing the sun, but larger, nearly 8,000 miles distant.

Now increase, in imagination, the diameter of the pea to 8,000 miles, and all the other diameters and the distances proportionately, and you have some idea of the immensity of space, and of the bodies which roll in space.

Illustration 12.—It will be seen by the above scale, that, with a globe six inches in diameter for the earth, in order to represent the sun of the proper size and at the proper distance, we should need, instead of this little glass globe, a sphere 54 feet in diameter, more than a mile off! The comparative sizes of the earth and moon, however, are correctly shown in the apparatus, the space between the centers being about $\frac{1}{30}$ of the relative distance. For the rest, the several planets are represented upon the internal surface of the "zodiac," as they would appear to an observer at the sun, moving through the sky *at the same apparent distance*—a table of their real distances and magnitudes being placed in a convenient position.

V.—HOW DISTANCES ARE MEASURED.

[Sec. II.—Chap. IV.]

(App. as in Fig. B, without Elevated Plane.)

Illustration 13.—Parallax and Distance of the Sun and Moon.—If we remove the glass globe, the end of the burner will represent the center of the sun. Now, viewing this center from one side of the earth, it will appear to us in a particular point upon this belt, or hoop, which represents a portion of the heavens. We will mark this point. Again viewing the center of the sun from the opposite point of the earth's surface, we see it in another point, at a little distance from the former. Let this point also be marked. The distance between these two points upon the belt, or hoop, represents the sun's apparent change of position, or *parallax*,* as viewed from opposite sides of the earth. If the sun were comparatively near us, as here represented, its parallax would be large; but, as its distance is immense compared with the earth's diameter, its parallax is correspondingly small.

Let the moon now be brought between the earth and sun. Its parallax, measured as above, is found to be very much greater than that of the sun; hence we know its distance to be very much less.

14. Parallax and Distance of the Stars.—1. Let a star be represented by some distant object in the room (as a gas-burner near the wall). Viewed from opposite points of the earth's surface, it is seen in precisely the same spot against the wall (sky), so far as we can see. Viewed from opposite points of the earth's orbit, however, it appears in slightly different positions against the wall. The distance between these positions may represent the parallax of the stars.†

It should be remarked that an object comparatively near is chosen to represent a star, in this illustration, in order that the *eye* may detect a parallax with the diameter of the earth's orbit as a base line. To represent the *real* comparative distance of the nearest star, an object more than 100 miles distant should be taken.

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* The parallax of the sun, moon, and planets given in tables, is their "*horizontal parallax*," that is, their change of position among the stars as seen in the zenith and horizon. Hence, in horizontal parallax, the base line is the *radius*, instead of the diameter of the earth.

† The "*annual parallax*" of the stars is measured from the *radius* of the earth's orbit.

2. Let the earth be represented by the small globe (Fig. C), and the north star, by the pin in the brass semi-circle attached at the solstitial points. Now, as the earth moves around the sun, its axis, extended, describes a small ellipse around this star. To observers upon the earth, however, the star appears to describe the ellipse around the extended axis. The longer diameter (major axis) of the ellipse corresponds to twice the *annual parallax* of the star (p. 11, note). Stars in other parts of the heavens describe ellipses of greater or less eccentricity, narrowing at the ecliptic to mere lines.

We see that the major axes of all these ellipses are equal to the diameter of the earth's orbit; and it must not be forgotten that, in consequence of their immense distance, they appear to ordinary observers as mere points, that is, the stars all appear "fixed"; hence the phenomenon here illustrated has, in fact, only a theoretical existence, save as applied to a few of the nearest stars.

VI.—THE EARTH'S ROTATION.

[Sec. IV.—Chap. I. and II.]

(App. as in Fig. A without Moon.—Earth at one of the Equinoxes.)

Illustration 15.—The Earth's Rotation is illustrated by the rotation of this globe upon the spindle which corresponds to the axis. We observe that it rotates once for each day marked on the dial.* In the meantime, however, we must bear in mind that the *real* axis of the earth is only a mathematical line, in comparison with which the finest spider-thread is infinitely thick. We shall often rotate this globe quite rapidly, but we must not forget that each rotation corresponds to a lapse of 24 hours.

16. Alternation of Day and Night.†—Let us select two conspicuous regions in the same latitude, but on opposite sides of the earth, as the U. S. and China, and follow each through a single rotation.

The U. S. are now just coming into the sunlight, while China is passing

* This accuracy is preserved only in the larger instrument.

† The illuminated portion of the earth may be distinguished from the shaded portion, either by the brass day-circle, or, in a darkened room, by using the artificial light. If the slated globe is now used, its surface should be whitened with chalk.

out of the sunlight. This causes the appearance of sunrise in the U. S., and sunset in China. One-fourth of a rotation brings the sun over the meridian (say, of N. Y. or Washington), and it is noon there, while in China it is midnight. Another quarter rotation, and it is sunset in the U. S., and sunrise in China. Another quarter rotation—midnight in the U. S., noon in China. The rotation finished, brings sunrise again to the U. S., and sunset to China.

VII.—THE EARTH'S YEARLY MOTION.

[Sec. IV.—Chap. III.]

Illustration 17.—The two Motions of the Earth, taking place at the same time and both from west to east, are represented by two corresponding movements of this globe. As it rotates, America appears to follow Europe *eastward* around it; and, as it revolves, its motion around the sun is seen to be in the same general direction, viz., from right to left, which, in the apparatus, corresponds to eastward motion.

18. The elliptical Form of the Earth's Orbit is shown by this elliptical groove in which the globe revolves. The degree of ellipticity is greatly exaggerated in order to present the *nature* of the curve to the eye. If the groove were of the actual form of the earth's orbit, it could not be distinguished from a circle, save by nice measurement. This glass globe represents the sun in one of the *foci* of the ellipse.

19. Perihelion and Aphelion.—We see that the earth is nearest the sun in winter—about the 1st of January, and most distant in summer—about the 1st of July. This line, connecting the perihelion and aphelion points, is called the *Line of Apsides.*

20. The changing Rate of Motion.—We read upon the plate within the circle (or rather, *ellipse*) bearing the names of the months, that the time from the vernal equinox to the summer solstice, is 92 days, 21 hours, 14 minutes; from the summer solstice to the autumnal equinox, 93 days, 13 hours, 34 minutes; from the autumnal equinox to the winter solstice, 89 days, 16 hours, 47 minutes; and from the winter solstice to the vernal equinox, 89 days, 1 hour, 42 minutes. Thus, the natural spring and summer are 7 days, 16 hours, 19 minutes longer than the natural autumn and winter, showing

that the earth moves a little faster in winter than in summer—at perihelion than at aphelion.

VIII.—HOW WE MAY WATCH THE EARTH'S REVOLUTION AROUND THE SUN.

[Sec. IV.—Chap. IV.]

(App. as in Fig. B.)

Illustration 21.—The Hollow Sphere of the Heavens is represented, in part, by this hoop and these movable circles encircling the earth and sun.

22. The Zodiac, or that part of the heavens through which the sun, moon, and planets move, is represented by the hoop, upon which the twelve signs are denoted by appropriate figures.

We see that the groups of stars, or constellations, bearing the same names as the signs, are unequal in their extent, and are about 30° west of the signs. The latter fact is due to the precession of the equinoxes, subject of Illustration 63.

23. The Ecliptic.—As the globe moves, we see that its center moves along the edge projecting from the inner surface of the zodiac. The center of the sun seems to move along the opposite part of the same edge. Accordingly, the edge (or rather, the line in which the plane cuts the zodiac, seen upon the outside) represents the *ecliptic*, or apparent path of the sun and real path of the earth in the heavens.

24. How we may read the Yearly Motion of the Earth from the Stars.—Let us mark our own position upon the globe, and move it to that point in its orbit corresponding to to-day. Then, to-night at midnight, we shall see these particular stars on the meridian. Now, if the earth did *not* move in its orbit, but merely turned on its axis, to-morrow night at midnight, we should see these same stars on the meridian; and so with the next night, and every night throughout the year. But, as the earth moves on in its orbit, we shall see, to-morrow at midnight, these stars on the meridian, instead of those which will appear there to-night. A month hence, we shall see these stars on the meridian; and so on throughout the year—different stars appearing on the meridian each night at the same hour; which could not be the case, if the earth had no movement in its orbit.

25. How the Sun seems to move along the Ecliptic, through the twelve Signs of the Zodiac.—If we could see the sun and stars at the same time, they would all appear at the same distance, viz., on the apparent surface of the sky. The sun, would, therefore, appear to be *among* those stars which are, in reality, many billions of miles *behind* it.

To-day, then, the sun would appear among these stars; and, if the earth did not move in its orbit, it would appear there to-morrow also, and every succeeding day. But, as the earth moves to this point, the sun appears to move along the ecliptic to the opposite point; and, accordingly, we see it among these stars. When, therefore, the earth has *really* completed its yearly revolution, the sun *seems* to have completed its yearly revolution through the twelve signs of the zodiac.

Thus, some of the stars which now twinkle on the meridian at midnight, will, in six months, be there at noon—exactly behind the sun. On the 22d of February, for example, the brilliant star Regulus is on the meridian at midnight: while on the 1st of September it is literally eclipsed, not by the sun's *rays*, but by the sun himself.

26. Sidereal and Solar Day.—Let us bring the point on the globe representing our own position, to noon. Then the center of the sun* and this particular star seem to occupy precisely the same spot on the meridian. Now let the earth's two motions go on, until the *star* is again on the meridian. This corresponds to the completion of a *sidereal* day, 23 hours, 56 minutes. But, in the meantime, the *sun* has moved 1 degree eastward, therefore it will require 4 minutes longer for him to reach the meridian, and complete the *solar* day of 24 hours.

27. Changing Appearance of the Heavens during the Year.—We actually see one-half the hollow sphere of the heavens at a time. If we substitute a smaller representation of the earth and its orbit (Fig. C) for the globe and elliptical groove, we shall see this illustrated. When the earth is in this point of its orbit, we shall see this half of the heavens at midnight. At the opposite point of the orbit, we shall see the opposite half †—the change being made, little by little, during the lapse of six months.

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* If the glass globe be removed, the tip of the burner will represent the center of the sun.

† The observer is supposed to be at the equator.

IX.—INCLINATION OF EARTH'S AXIS TO THE PLANE OF THE ECLIPTIC.

[Sec. V.—Chap. I.]

Illustration 28.—The Plane of the Ecliptic, or plane of the earth's orbit, is represented, in part, by this oval plate, which, if uninterrupted, would cut through the centers of both sun and earth. This edge, projecting from the zodiac, is nothing more than the same plane continued beyond the earth's orbit, and cutting the sky in the ecliptic, or middle line of the zodiac. As we revolve the earth around the sun, we see that its center never rises above or sinks below this plane; and also that an observer at the earth's center would see the center of the sun always in the same plane.

29. The Ecliptic drawn around mapped Globes.—If we slowly rotate the mapped globe, we shall find that there is only one position in which this circle coincides with the plane of the ecliptic. In fact, there is little propriety in drawing this celestial circle upon globes, and its only use is to show the *amount* of the inclination of the equator to the ecliptic.

30. Inclination and constant Direction of the Earth's Axis.—The spindle corresponding to the earth's axis is inclined $23\frac{1}{2}°$ to the perpendicular, and, consequently, $66\frac{1}{2}°$ $(90—23\frac{1}{2})$ to the plane itself.

If we notice toward what part of the ceiling it is now pointing, we shall see that it continues to point toward the same part during the whole revolution in the orbit. The *exact spot*, however, toward which it points, is seen to move around in an ellipse in the ceiling, as the globe moves around the dial. But this is because the ceiling is so near. If the roof were removed, and a distant cloud were substituted for the ceiling, the ellipse would seem to be so diminished by the distance that it would appear to be an immovable point, like the north pole of the heavens. (See Illust. 14, 2.)

31. The Equinoctial.—To represent this, we must bring the earth to one of the equinoxes, and raise the brass semi-circle which is attached at the equinoctial points, until it is parallel with the line marked "equinoctial" upon the outside of the zodiac. We see that it lies exactly over the earth's equator, and is inclined $23\frac{1}{2}°$ to the zodiac and ecliptic, and that, from the

present position of the earth in its orbit, the sun appears to be at one of the points in which the ecliptic crosses the equinoctial, viz., an *equinox*.

(In order that this brass semi-circle may correctly represent the equinoctial when the earth is in other points of its orbit, the small globe, Fig. C, must be used, the reason for which is obvious.)

X.—THE SUN'S DECLINATIONS.

[Sec. V.—Chap. II.]

Illustration 32.—The Tropics and Equator indicated by the Sun's Vertical Rays.—The sun's vertical rays fall where the plane of the ecliptic cuts the earth's surface at the point nearest the sun. If, then, we rest a crayon upon this plane, with its point touching the globe while it rotates, it will draw the equator at the equinoxes, the tropic of Cancer at the summer solstice, and the tropic of Capricorn at the winter solstice.

33. The Polar Circles and Poles indicated by the Sun's most oblique Rays.—The brass day-circle shows where the sun's most oblique rays fall. If we apply the crayon at that point under the day-circle which is nearest the north pole, and then rotate the globe, the crayon will draw the arctic circle at the solstices; while, at the equinoxes, it will remain stationary at the poles.

34. The Sun's Daily Circuits, and Spiral Path around the Earth.—If we keep the crayon constantly applied where the vertical rays fall, and produce the two motions, we shall see that the sun's daily path around the earth, as thus marked, is a different circle each day, and also that its yearly path is a *spiral* winding from tropic to tropic, and back again, like a thread winding upon a spool.

35. Derivation of the Names of the Tropics—When the sun is vertical at the tropic of Cancer, we see it in the sign Cancer. When it is vertical at the tropic of Capricorn, we see it in the sign Capricornus. During the earth's yearly revolution, we see the sun appear to move to one tropic, then *turn*, and move to the other tropic; this explains the significance of the word *tropic*, which is derived from a Greek word meaning a *turning point.*

36. Visible Constellations of the Zodiac low in Summer, and high in Winter.—At the summer solstice, we see the sun almost directly overhead at noon. Now, as the globe rotates and our position comes round to the midnight point, that constellation of the zodiac which

is opposite the sun, appears low in the south. At the winter solstice the relative positions are reversed.

XI.—THE CHANGE OF SEASONS.—THE VARIATION IN THE LENGTH OF DAY AND NIGHT.

[Sec. V.—Chap. III.]

Illustration 37.—The Change of Seasons.—The different directions in which the sun's rays fall at any place during the year, thus producing differences in temperature, are best shown by fixing some small pointed object upon the globe, with its point exactly toward the center. If this object represent a person standing upon the earth, it will be obvious that at the summer solstice the person thus represented sees the sun almost overhead at noon, and that at the winter solstice he sees it, at noon, comparatively low in the southern sky; while during the intermediate time he sees it at different points between these two.

38. Varying Length of Day and Night.—If we attach the brass day-circle, or boundary line between day and night, mark a spot upon the globe to represent our own position, and draw a parallel circle through that point, we shall see that at the summer solstice much more than half the parallel is in the sunlight, that is, that we are much longer in passing through the sunlight than through the shade. From the summer solstice we shall see the day growing shorter and the night longer until the autumnal equinox, when they will be equal. Thence, we shall see the night growing longer than the day until the winter solstice, when the day will begin to lengthen.

39. Day and Night always equal at the Equator, and differing according to the Distance from the Equator.—Repeating the last experiment without confining our attention to our own position upon the globe, we see that at the equator itself day and night are always equal, and that the difference grows greater, the farther we depart from the equator.

For example, at the point immediately south of the arctic circle, the night is but an instant in length at the summer solstice—the remainder of the twenty-four hours being day.

40. Twenty-four Hours' Day and Night within the Polar Circles.—At the solstices, one frigid zone remains constantly in the sunlight during the earth's daily motion, while the other frigid zone remains constantly in the shade. We see also that the circle of continuous day and night diminishes each day from solstice to equinox, and *vice versa.*

41. Six Months' Day and Night at the Poles.—We see the north pole constantly in the sunlight, and the south pole as constantly in the shade, from the vernal equinox to the autumnal equinox; and the opposite conditions during the remainder of the year.

If we now remove the globe from the spindle, and convey it around the sun with its axis perpendicular to the plane of the ecliptic, we shall see the sun always over the equator, and none of the changes illustrated in the last two sections taking place.

XII.—THE MOTIONS OF THE MOON.

[Sec. VI.—Chap. I.]

(*App. as in Fig. A, without Brass Circles.*)

Illustration 42.—The Moon's Orbit.—The lunar globe describes an elliptical orbit around the terrestrial globe. This point corresponds to *perigee,* and this, to *apogee.*

43. *Nodes.*—At about this point, it begins to ascend above (north of) the plane of the ecliptic, and hence this point corresponds to its *ascending node.* From this point, it descends below (south of) the plane of the ecliptic, and hence this point corresponds to its *descending node.*

44. Sidereal and Synodic Revolutions.—Let some distant object represent a star. The apparatus must now be arranged so that the star, sun's place, and moon, as seen from the earth, shall appear together, or in the same line. As the moon now performs one complete revolution around the earth, she appears to return to the star, and, therefore, has performed a *sidereal* revolution. But, in the meantime, the sun's place has gone one sign eastward, and so the moon must move *this* distance farther before completing her *synodic* revolution. If we observe the index upon the dial, we shall see

that it requires 27⅓ days to complete the sidereal revolution, and a little more than 2 days longer to complete the synodic revolution.

45. *Number of Revolutions during the Year.*—If we count the sidereal revolutions of the moon during the yearly revolution of the earth, we shall find them a fraction over 13; while we shall count only a fraction over 12 synodic revolutions. It will be noticed that the sidereal revolutions are exactly *one more* than the synodic. This would be the case whatever the number of the former. If, for example, the moon performed two sidereal revolutions in a year, she would perform only one synodic revolution in the same time.

46. The Phases of the Moon may be effectively imitated with the aid of the artificial light. In order to see them in their proper order, the observer should, of course, be upon the terrestrial globe. The same *general effect*, however, may be produced by using the terrestrial globe for the moon, and revolving it around the light. Different portions of the lighted half will thus be presented to view, and will assume, in turn, the crescent, half, gibbous, and full forms.

47. The Moon rises about an Hour later each Day.—Let us mark a spot upon the earth for our own position, then turn the globes until noon is represented at this spot, and the moon is seen from it exactly in the eastern horizon (that is, in a straight line in the direction in which the spot is turning). The moon is now represented as rising precisely at 12 o'clock, noon. Now, if we produce all the motions until our position has come round to noon again, the lapse of one day will be represented; but the moon will now be *below* the horizon, and will not rise until nearly an hour *after* noon. In this Illustration her orbit is supposed to be vertical.

48. The Moon's Rotation.—If that half of the moon which is next the earth be whitened with chalk, and a revolution be produced, the whitened half will be seen always to face the earth. The moon will be seen to turn upon its axis once in the mean time, from the fact that this whitened half is turned successively toward all sides of the room.

49. The Full Moon runs "high" and "low."—To represent the full moon, the lunar globe must be on that side of the earth opposite the sun. At the summer solstice, we see the sun almost overhead when our position comes to the noon point. Now, as this spot turns round to the moon, the latter is *seen quite* low. At the winter solstice, we see these appearances reversed.

XIII.—ECLIPSES.

[Sec. VI.— Chap. II.]

Illustration 50.—Rare Occurrence of Eclipses.—As we move these globes, the shadow of one falls upon another at every synodic revolution of the moon. This is because the globes are so large, compared with the distances between them. If they were very much reduced, it is evident that this would not be the case. That long intervals elapse between eclipses, may be illustrated, therefore, by substituting the small globes represented in Fig. F, p. 31. For example—the moon is now full, but it is not at a node, *i. e.*, crossing the ecliptic; hence there is no eclipse. The moon is now at a node, but it is neither full nor new—no eclipse.

To exhibit other phenomena, the larger globes must now be replaced.

51. Solar Eclipses.—Let us move the globes until their centers are in a straight line, with the moon between the other two. This is the proper arrangement for the representation of a *solar eclipse.*

The moon is new, and at the same time at a node. The diameter of the *umbra* is less than the moon's diameter, showing that the form of her shadow is conical.* From an observer within the *umbra*, the sun's direct rays are entirely cut off, and he witnesses a *total eclipse.* From an observer within the *penumbra*, only a part of the sun's direct rays are cut off, and he witnesses a *partial eclipse.* An observer in the eastern part of the *penumbra* sees the western part of the sun's disk obscured; one in the western part of the *penumbra* sees the eastern part of the sun's disk obscured, etc. As the earth rotates, we see the moon's shadow passing over a narrow section of (*name the countries*, *oceans*, *etc.*). The eclipse is visible, therefore, only within that section of the earth's surface.

52. Lunar Eclipses.—Let us now move the globes until they are again in a line, with the earth between the other two. We have now an imitation of a *lunar eclipse.* The diameter of the earth's shadow being much greater than the moon's diameter, a total eclipse is visible from all parts of the unen-

* If the artificial light is sufficiently bright, and the surface of the terrestrial globe quite white, the *umbra* and *penumbra* will be distinctly defined.

lightened hemisphere of the earth. As the globes move, the moon is seen to enter the earth's shadow on the western side, and emerge from it on the eastern side. These are called its 1st and 2d "*contacts*" with the *umbra*. At each of these times, an edge of the earth's circular shadow is seen, which constitutes one of the most satisfactory proofs of its spherical form.

XIV.—TIDES.

[Sec. VI.—Chap. III.]

Illustration 53.—Comparative Height of the Tides.—*Problem*:—How much should the surface of this globe be elevated to represent the greatest height to which the tides ever rise?

Ans. 8,000 miles : 70 feet : : 6 inches : $\frac{1}{100,000}$ of an inch (nearly). To represent the *average* height of the tides, the elevation should be less than $\frac{1}{20}$ of this.

54. Spring-Tides.—Imagine the solar tides on opposite sides of the globe, on a line with the sun; and the lunar tides, on a line with the moon. At new moon, the solar and lunar tides are together. We must, therefore, suppose the water slightly elevated upon these two sides of the globe, and correspondingly depressed upon these two sides.

55. Neap-Tides.—As the motions proceed, we see the solar and lunar tides separating until the moon is in quadrature, when they are farthest apart, and "high-water" is comparatively low.

56. Ebb and Flow of the Tides twice a Day.—Let us observe the changes at New York during one rotation of the earth, beginning with high-water. As the rotation slowly goes on, the tide gradually falls—until it is now at the lowest ebb. It now begins to rise—is again at high-water-mark—ebbs again —low-water—flows—high-water.

57. Tides nearly an Hour later each Day.—Let us bring New York to the noon-point, with the sun and moon in the same line. This represents high-tide taking place at noon at New York. Let the motions go on until it is *again* noon at New York. We see that the moon, in the mean time, has moved a little eastward, so that it will not be high-tide again at New York until nearly an hour *after* noon. See Ill. 47.

XV. THE TROPICAL YEAR, ETC.

[Sec. VII.—Chap. II and III.]

Illustration 58.—How the Ancients measured the Tropical Year.—Let a small object be fixed upon the globe to represent an upright object upon the earth at our own position. Now, if the artificial light is used, we shall see the shadow considerably longer at noon at the winter solstice, than at noon on any other day. As the earth moves around in its orbit, we see the noon-shadow gradually shortening until the summer solstice, then lengthening again until the winter solstice. It was by measuring the time between two returns of the longest or shortest noon-shadows, that the ancients measured the length of the *tropical year*.

59. The Epact.—During the revolution of the earth now represented, let us observe on what day of December the moon happens to come between the earth and sun. The remaining days of December will be the moon's age at the beginning of the following year, or, in other words, the *epact* for that year.

From this, we can find the moon's age for any day during the year. Thus, if the epact is about 15 days, the moon will be full about the 1st of the month for several months.

XVI. WHERE THE DAYS BEGIN.

[Supplement I.]

Illustration 60.—Let us bring New York to the noon-point. Suppose this to be the noon of to-day. Then we find it, at the same instant, 6 o'clock this evening in Southern Italy, and 12 o'clock to-night at Birmah. East of Birmah, we find it *after* midnight, and, therefore, to-morrow. Proceeding eastward from Birmah to Alaska, we find it 6 o'clock to-morrow morning. Still farther east, according to the general law, it is still later; and, on arriving at New York we find it to-morrow noon.

It cannot, however, be both to-day and to-morrow at once in the same place. Somewhere in our imaginary journey, we must have returned from

to-morrow to to-day, that is, we must have crossed a certain line dividing to-morrow from to-day. That line is a meridian passing through Alaska. Navigators, however, change the date at long. 180° from Greenwich.

Therefore, on arriving again at New York, from our imaginary journey around the world in an instant of time, we shall find it still to-day, as when we started.

XVII.—SUN-TIME AND CLOCK-TIME.

[Supplement II.]

Illustration 61.—As the earth reaches this point in its orbit, April 15th, the sun and clock agree; but, as the earth moves on, the solar days are a little less than 24 hours long, and, consequently, the sun is "fast of the clock." Presently, however, the solar days begin to lengthen, which gives the clock an opportunity to overtake the sun, and they agree again on the 15th of June. After this, the sun is "slow" until the 1st of September—then "fast" until about Christmas.

62. The two Causes of the Differences in the Length of the Solar Days.—1. *Varying Rate of Sun's apparent Motion.*—Illustration 20 showed us that the sun seems to move along the ecliptic at different rates at different times; and Illustration 26, that it is this apparent movement of the sun which causes the solar day to be longer than the sidereal day. Since, then, there is a difference in this apparent movement, there must be a corresponding difference in its *result;* hence the solar day is not *so much* longer than the sidereal day, at some times as at others.

2. *Inclination of the Equinoctial to the Ecliptic.*—Let the earth be brought near an equinox. As it moves in its orbit here, the sun's apparent path is seen to cross the equinoctial at an angle of 23½°. But the equinoctial (or equator) extends *directly east and west* around the earth; therefore the sun seems to move, not exactly east, here, but in a line *inclined* 23½° *to the east line.*

Let the earth now move near a solstice. It will be seen that the sun's apparent movement along the ecliptic is now very nearly *parallel* with the equinoctial, that is, *almost directly east.* But we have seen (Ill. 26) that it

is the sun's apparent daily *progress eastward*, that causes the solar day to be longer than the sidereal day. Since, then, he seems to move sometimes directly east, and at other times north-east or south-east, it follows that, although the solar day is *always* longer than the sidereal day, the excess is not always the same.

XVIII.—PRECESSION OF THE EQUINOXES.

[Supplement III.]

(*App. as in Fig. B.—Earth as in Fig. C.*)

Illustration 63.—By turning this little globe in its support, we may produce a *gyrating movement* of its axis, like that observed in the axis of a top, when inclined from a perpendicular.

As a combined result of the earth's rotation and the sun's unequal attraction for the swelling at the equator, the earth's axis makes a similar movement, the gyration being completed once in about 26,000 years.

If we now produce this motion slowly from right to left, at the same time moving the zodiac so that the north pole of the heavens (Ill. 66) *shall always cover the north pole of the earth*, we shall see : —

(1.) The north celestial pole describing its circle, 47° in diameter, around the north pole of the ecliptic (Ill. 68).

(2.) The equinoctial points moving westward around the ecliptic.

(3.) The signs passing the constellations of the zodiac from east to west. (For this Illustration, the latter are indicated within the dark circle upon the base of the instrument.)

Let us now arrange the zodiac so that the signs shall agree in position with the constellations. We must also direct the earth's axis toward the north celestial pole. As thus arranged, the apparatus represents the relative positions of the earth, celestial pole, signs and constellations of the zodiac about 2,100 years ago. As we now restore the parts to their usual places, we represent the amount of precession that has taken place since the zodiac was constructed by the ancient astronomers.

XIX.—DIVISION OF CELESTIAL SPHERE.

[Supplement IV.]

Illustration 64.—The Horizon System of Circles.—To illustrate this topic, we may use the hoop which has heretofore served to represent the zodiac, and the elevated plane which has represented the plane of the ecliptic. If an observer be supposed to stand in the center of this plane, it will represent the plane of his horizon, and the line in which it cuts the hoop will represent the horizon itself. The brass semi-circles, raised to an upright position, will represent two verticals, and the point in which they cross each other, the zenith. If the points at which one of the semi-circles is attached, serve for the north and south points, it will correspond to the meridian, while the other semi-circle will correspond to the prime vertical.

65. *Measurements.*—Altitude may be measured from the horizon on one of these verticals; zenith-distance may be measured from the zenith on the same; azimuth is measured on the horizon from the meridian, in either of these four directions; amplitude, from the prime vertical, in either of these four directions.

66. The Equinoctial System.—We must now restore to this plane and hoop their usual significance. Then, the north pole of the little globe being inclined toward the sign Cancer, the equinoctial is represented as in Illustration 31. The semi-circles crossing each other over the north pole of the earth, represent the equinoctial and solstitial colures (two right-ascension meridians), and their point of crossing, the north celestial pole. Declination parallels would be represented by circles drawn around these meridians parallel to the equinoctial.

67. *Measurements.*—Declination is measured from the equinoctial on any meridian, for example, the solstitial colure. Thus, we find the star *Antares* in 25° south declination. Polar-distance is measured from the pole on a meridian. Thus, we find the polar-distance of the star *El Nath* to be 62°. Right-ascension is measured eastward on the equinoctial from the vernal equinox, entirely round to the vernal equinox again. Thus, we find the right-ascension of the star *Aldeb'aran* to be about 60°.

68. The Ecliptic System.—If we raise the semicircles to an upright posi-

tion, they will represent two circles of celestial longitude, and their point of crossing, the north pole of the ecliptic, $23\frac{1}{2}°$ distant from the north pole of the heavens. Circles drawn around these semi-circles parallel to the ecliptic will represent parallels of celestial latitude.

69. *Measurements.*—Celestial latitude may be measured on one of these circles of celestial longitude. Thus, we find the north pole of the heavens in latitude $66\frac{1}{2}°$. Celestial longitude is measured on the ecliptic eastward from the vernal equinox. Thus, we find the star *Spica* in longitude 200°.

XX.—THE SOLAR SYSTEM.

[Supplement V.]

Illustration 70.—The Solar System.—Our instrument exhibits the sun and a specimen planet with an attendant moon, revolving around it. The other planets are represented pictorially upon the inner surface of the zodiac. To all these belong motions, similar to those we have witnessed in the earth. Their axes have different degrees of inclination to the planes of their orbits—some more and some less than that of the earth, and all maintain a constant direction. Consequently, a change of seasons and a variation in the length of day and night occur in each, differing in degree according to their axial inclination. Each season, however, in the most distant planets is much longer than our entire year; while in Mercury, the planet nearest the sun, the entire year is shorter than one of our seasons. In each planet, having one or more moons, the plane of its own orbit is the plane of the ecliptic; while its own equator, projected on the sky, forms the equinoctial. The superior planets generally have several moons, while the inferior planets have none. Hence, in the former eclipses are frequent, while in the latter they are un-unknown.

71. The Orbits of the Planets are more or less inclined to one another, as shown by the white lines. Viewed from the sun, Mercury is seen to cross the earth's orbit at an angle of 7°—pass through half the zodiac—recross the earth's orbit—and finish its revolution in 88 days. The orbit of Venus is inclined $3\frac{1}{3}°$ to the ecliptic; its period is 225 days. Mars, inclination 2°; period, 687 days. Jupiter, inclination $1\frac{1}{3}°$; period, 4,333 days. Saturn, in

clination $2\frac{1}{2}°$; period 10,759 days. Uranus, inclination $\frac{3}{4}°$; period 30,687 days. Neptune, inclination $1\frac{3}{4}°$; period 60,127 days.

The orbits of the asteroids are generally much more inclined to the ecliptic than those of the major planets, often passing far beyond the limits of the zodiac. A cometary orbit may lie in almost any direction.

Viewed from the earth, the motions of the planets, etc., in the zodiac, appear more or less complicated in consequence of the earth's own motion.

72. Direct (forward) and Retrograde Motions of an Inferior Planet.—We may suppose this little globe (Fig. C) to be an inferior planet. From the sun we see it moving always *forward* through Aries, Taurus, Gemini, etc. But, when we view it from the earth, it appears to move forward through the more distant portions of its orbit, and *baekward* through the nearer portions.

73. Conjunctions and Elongations of an Inferior Planet.—At this point, between the sun and earth, it is in inferior conjunction ; at this point, behind the sun, in superior conjunction. At this point, where it appears farthest east of the sun, it is at its extreme eastern elongation ; at this point, it is at its extreme western elongation.

74. An Inferior Planet as Morning and Evening Star.—While moving from superior to inferior conjunction, it appears west of the sun, and is, therefore, morning star. During the rest of the revolution, it is evening star.

75. Conjunction and Opposition of a Superior Planet.—We will now suppose the little globe to be the earth, and the large globe to be a superior planet. When the sun is between the two planets, the superior planet is in conjunction. When the earth is between the sun and superior planet, the latter is in opposition.

76. A Superior Planet as Morning and Evening Star.—While approaching conjunction, the superior planet appears west of the sun, and is, therefore morning star. While moving from conjunction, it is evening star. It will we remembered that the orbital motions of the superior planets are comparatively slow, hence the various effects described in this section, should be produced chiefly by the movement of the globe representing the earth.

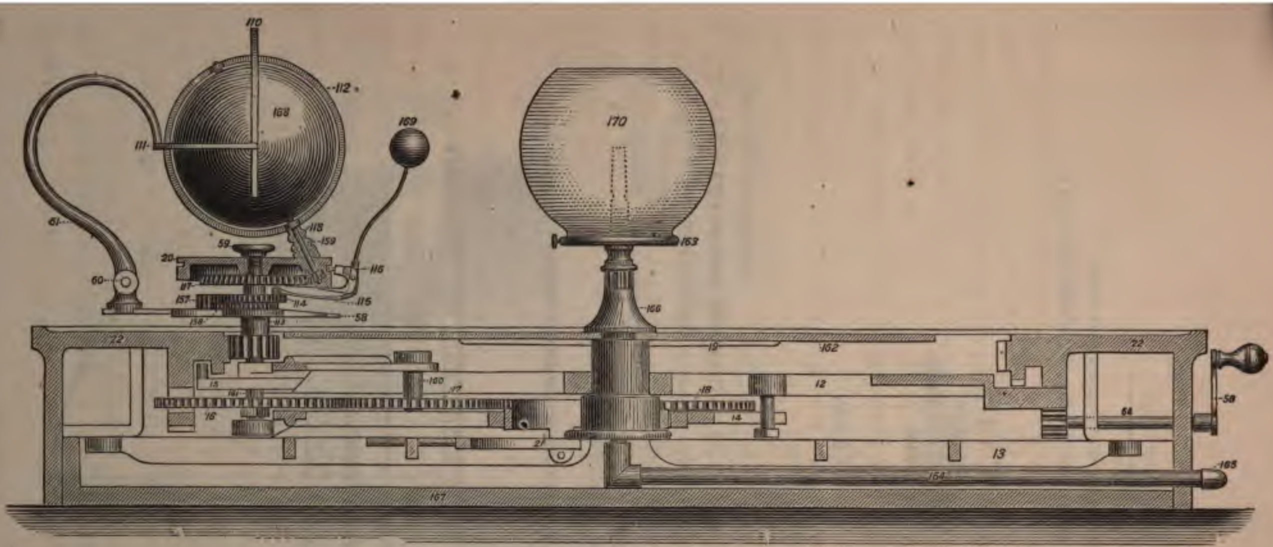

Figure D.

12. Large crown wheel, or driving gear.
13. Spider with four arms to support 12.
14. Sliding ring and cross for carrying 16, 17, 18 forward and backward in the ellipse.
15. Cross above the same.
16, 17, 18, Cog-wheels for preserving parallelism of earth's axis.
19. Cast-iron bearing riveted to 162.
20. Inverted cup under terrestrial globe.
21. Stirrup securing 16, 17, 18.

58. Index for dial.
59. Nut securing 20.
60. Thumb-screw securing 61.
61. Goose-neck support for day-circle.
64. Crank-shaft with worm or pinion.
110. Day-circle.
111. Semi-circle supporting 110.
112. Meridian circle.
113. Hollow cylinder with two cog-wheels.
114, 157, 158, Cog-wheels driving lunar globe.

118. Brass post supporting globe.
157, 158. See 114.
159. Spindle for terrestrial globe.
161. Shaft
162. Oval plate for dial.
163. Support for glass shade.
164. Gas-pipe.
165. Gas-coupling.
166. Pedestal for burner.
167. Wooden bottom.
168. Terrestrial globe.

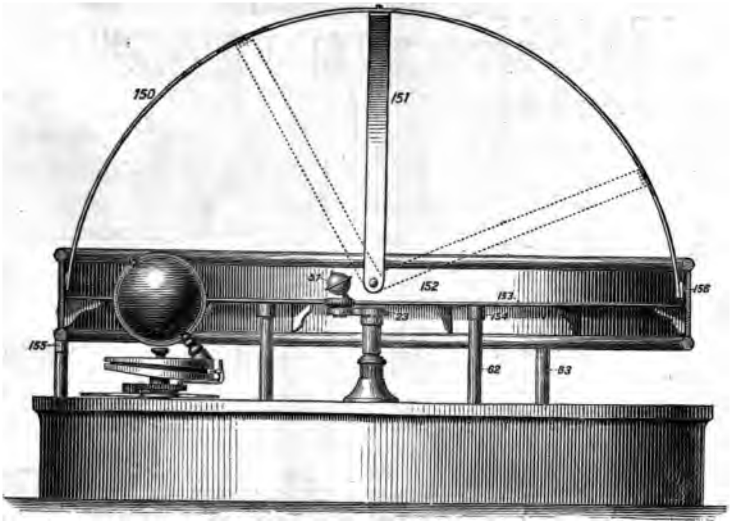

Figure E.

23. Support for small globe, attached to gas burner.
57. Small terrestrial globe.
62. Legs for elevated plane.
63. Legs for zodiac.

150, 151, Celestial circles.
152. Zodiac.
153. Elevated plane.
154, 155, Female screws.
156. Bearings for celestial circles.

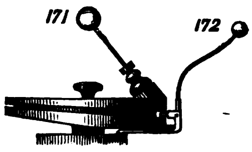

Figure F.

171, 172, Small terrestrial and lunar globes attached to 20, to show moon's nodes and the rare occurrence of eclipses.

(51 numbers in all.)

STAND FOR THE STELLAR TELLURIAN.

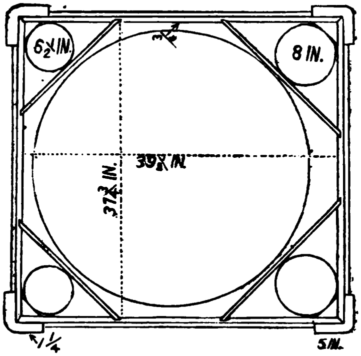

Fig. G.

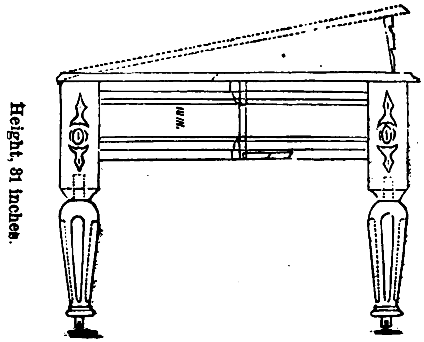

Fig. H.

Above is a working plan for a table suitable for supporting the instrument when in use, and containing it at other times. Fig. G shows the inside, with five compartments. As it is often desirable to incline the instrument when exhibiting to a class, the cover may be raised and secured by a ratchet, as shown in Fig. H. The dimensions given are such as will accommodate the larger instrument. For the smaller, take one-half each interior dimension, with the exception of the depth (Fig. H), which should be six inches. For convenience in transporting, the legs may be detached and packed lengthwise under the table.

The table will be sent with the instrument, if desired, all in one box, at prices varying from $8 to $20 extra for larger size, and from $6 to $14 for smaller; or it may be easily made by any cabinet maker from the above plan.